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November 16, 2020

VIA ECFS

Marlene H. Dortch, Secretary
Federal Communications Commission
45 L Street, NE
Washington, DC 20554

Re: *Notice of Ex Parte Communication*: Unlicensed Use of the 6 GHz Band, ET Docket No. 18-295; Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz, GN Docket No. 17-183

Dear Ms. Dortch:

On November 12, 2020, representatives of the 5G Automotive Association ("5GAA") spoke by telephone with Ron Repasi, Ira Keltz, Dr. Monisha Ghosh, Jamison Prime, Michael Ha, Barbara Pavon, Nicholas Oros, Navid Golshahi, and Bahman Badipour, all of the Commission's Office of Engineering and Technology, regarding the record in the above-referenced proceeding. The following representatives of 5GAA member companies participated in the call:

- **Ford Motor Company**: John Kwant, Ivan Vukovic, Nick Baracos, Gurunath Vemulakonda
- **Nokia**: Jeffrey Marks
- **Panasonic**: Paul Schomburg, Michael Stelts
- **Qualcomm**: Dean Brenner, John Kuzin, Tevfik Yucek, Aasif Dingankar

5GAA was also represented by Mark Settle and the undersigned, both of Wilkinson Barker Knauer, LLP.

5GAA discussed the importance of protecting Cellular Vehicle-to-Everything ("C-V2X") safety services in the adjacent 5.9 GHz band. Last year, 5GAA submitted real-world testing results demonstrating that a very low power ("VLP") device or mobile access point located within a vehicle and operating in the lowermost U-NII-5 channel would substantially degrade C-

V2X performance if permitted to radiate out-of-band emissions ("OOBE") of -27 dBm/MHz.[1] These unwanted emissions reduce the range of C-V2X Direct communications, rendering safety services less effective.[2] Range reductions can be as high as 50% for each 6 dB of unwanted noise from VLP operations, and 20 dB of unwanted noise can reduce C-V2X Direct range by as much as 90%.[3]

Recent testing by the CAMP Cellular V2X Device-to-Device Communication Consortium ("C-V2X Consortium") confirms the inadequacy of an OOBE level of -27 dBm/MHz for U-NII-5 portable operations.[4] While the C-V2X Consortium testing evaluated a different OOBE mask—the Wi-Fi Alliance's proposal for U-NII-4 outdoor operations[5]—its results can be translated to assess the -27 dBm/MHz root mean squared ("rms") OOBE limit for

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[1] *See* 5GAA, *6 GHz Out-of-Band Emissions (OOBE) Limits—Testing of Impact of Proposed U-NII-5 Unlicensed Devices on C-V2X Receiver Sensitivity* (Dec. 9, 2019), attached to Letter from Sean T. Conway, Counsel for the 5G Automotive Association, to Marlene H. Dortch, Secretary, Federal Communications Commission, ET Docket No. 18-295 & GN Docket No. 17-183 (filed Dec. 9, 2019).

[2] *See* Comments of the 5G Automotive Association, ET Docket No. 18-295 et al., at 5 (filed June 29, 2020) ("5GAA Comments").

[3] Mitigation techniques cannot substantially offset the impact of these unwanted emissions either. For instance, while C-V2X antenna diversity can provide some relief, the amount of gain from diversity is not nearly sufficient to counter the impact from these in-vehicle unlicensed operations. *See* Letter from John F. Kwant et al., 5GAA US Task Force Chair, to Marlene H. Dortch, Secretary, Federal Communications Commission, ET Docket No. 18-295 & GN Docket No. 17-183, at 2 (filed Jan. 24, 2020). Similarly, the impact of unwanted emissions cannot be addressed merely through C-V2X antenna placement on vehicles. Vehicle manufacturers require the flexibility to integrate C-V2X antennas in locations where a reliable signal propagation path can be established, and the location of each installation will vary by vehicle type.

[4] *See* Cellular V2X Device-to-Device Communication Consortium, *Task 8: Assessment of Wi-Fi Interference to C-V2X Communications Based on Proposed FCC 5.9 NPRM* (Sept. 28, 2020) ("C-V2X Consortium V2V/V2I Report") (attached as Attachment 1), https://pronto-core-cdn.prontomarketing.com/2/wp-content/uploads/sites/2896/2020/09/CAMP-CV2X-WiFi-Interference-Testing-Results-v6.11.3.pdf.

[5] *See* Cellular V2X Device-to-Device Communication Consortium, *Task 8: Assessment of WiFi Interference to C-V2X Communication Based on Proposed FCC 5.9 GHz NPRM*, at 8 (Apr. 15, 2020) ("C-V2X Consortium Wi-Fi Characterization & Bench Testing Report") (attached as Attachment 2), https://pronto-core-cdn.prontomarketing.com/2/wp-content/uploads/sites/2896/2020/04/CAMP-CV2X_Project_Task_8_Final_04242020.pdf.

U-NII-5 portable devices. These translated results demonstrate that in-vehicle U-NII-5 devices operating under a -27 dBm/MHz rms OOBE limit will impact C-V2X operations in the 5905-5925 MHz band slightly more so than in-vehicle U-NII-4 devices operating under the Wi-Fi Alliance's proposed outdoor OOBE mask. 5GAA distributed the attached presentation explaining its methodology for this translation.[6]

As 5GAA explained in the 5.9 GHz proceeding, the C-V2X Consortium V2V/V2I Report demonstrates that in-vehicle U-NII-4 devices operating under the Wi-Fi Alliance's proposed outdoor OOBE mask significantly degrade C-V2X performance. For example, C-V2X's effective range was reduced by more than 50% in many cases when subject to harmful unwanted emissions from U-NII-4 in-vehicle operations. The following chart summarizes the C-V2X Consortium V2V/V2I Report's results for scenarios involving a roof-mounted C-V2X antenna[7]:

Communication Range (@ PER < 10%)								
	Approaching				Separating			
TEST SCENARIOS	CH 180		CH 183		CH 180		CH 183	
	No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot
V2V NLOS	160 m	50 m	160 m	100 m	180 m	40 m	170 m	90 m
I2V NLOS	440 m	70 m	520 m	150 m	600 m	110 m	530 m	220 m
V2V NLOS Intersection	420 m	40 m	610 m	110 m	380 m	50 m	590 m	190 m

[6] *See* 5GAA, *Protecting 5.9 GHz C-V2X operations from 6 GHz unlicensed In-Vehicle VLP and Mobile Hotspots in the U-NII-5 band* (Nov. 12, 2020) ("5GAA Presentation") (attached as Attachment 3).

[7] C-V2X Consortium V2V/V2I Report at 26.

As referenced above, a -27 dBm/MHz rms mask for U-NII-5 VLP and mobile hotspot operations would pose slightly worse impacts to C-V2X in Channel 183.[8]

5GAA also explained the assumptions that went into its translation analysis and the C-V2X Consortium's testing. *First*, 5GAA explained its basis for prescribing a 10+ dB difference between peak and average OOBE levels. Modern OFDM based systems are known to have a minimum of 10 dB peak to average power ratio ("PAPR") within the in-band portion of the signal. According to publicly available data[9] and measurements taken by the C-V2X Consortium, the PAPR in the out-of-band portion of the signal is slightly higher than the in-band portion. For simplicity and ease of comparison, 5GAA used a fixed value of 10 dB for the out-of-band portion in its analysis.[10] This 10+ dB difference between peak and average levels was also confirmed via actual measurements provided in the C-V2X Consortium testing results. Specifically, the interference source used in the C-V2X Consortium Wi-Fi Characterization & Bench Testing Report was configured to provide a flat OOBE limit of -17 dBm/MHz peak over the 5905-5925 MHz C-V2X channel.[11] RMS average OOBE measurements taken over this channel were -29.84 dBm/MHz.[12] These measurements, shown in the diagrams below, demonstrate that the analysis presented in the 5GAA slide deck holds, for the measured interference level was lower than the -27 dBm/MHz rms limit used in the analysis.

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[8] *See* 5GAA Presentation at 3.

[9] *See* Wireless Innovation Forum, *Part 96 Emission Measurements Procedures*, at 22-23, (Dec. 3, 2015), https://winnf.memberclicks.net/assets/work_products/Recommendations/WINNF-15-R-0092-V1.0.0%20%20Emission%20Measurement%20Ex%20Parte.pdf.

[10] *See* 5GAA Presentation at 5.

[11] C-V2X Consortium Wi-Fi Characterization & Bench Testing Report at 18.

[12] *Id.*

Second, the C-V2X Consortium testing used a typical scenario for isolation between the C-V2X antenna and the Wi-Fi transmitter. Specifically, the majority of testing was performed with C-V2X antennas located on the vehicle roof, which allows for greater isolation than other scenarios involving an in-cabin Wi-Fi transmitter. As 5GAA previously has explained, roof-mounted C-V2X antennas may not be possible for many common vehicle types (*e.g.*, convertibles, motorcycles, vehicles with roof racks, etc.).[13] Isolation decreased by 4 dB when C-V2X antennas were located on outside mirrors, and would decrease even further if these antennas are located behind the rearview mirror.[14]

Finally, it is reasonable for interference analyses involving C-V2X safety services to assume a high-activity factor for U-NII-5 devices. Almost any particular device can be operating

[13] *See* 5GAA Comments at 6.

[14] Notably, unwanted emissions substantially impacted C-V2X performance in scenarios involving both roof-mounted and outside mirror-mounted C-V2X antennas.

with a high-activity factor at any time when located in a vehicle.[15] In addition, filings from unlicensed proponents suggest dramatic increases of in-vehicle unlicensed operations in the near future. For instance, unlicensed proponents not only project the introduction of millions of Wi-Fi connected devices *and* high-bandwidth applications such as Virtual Reality and Augmented Reality, but also freely acknowledge that operations inside vehicles will be a major use case for portable U-NII-5 devices.[16] Moreover, the very foundation of arguments to open this band is grounded in the notion that congestion in other unlicensed spectrum bands necessitates new unlicensed opportunities here.

It reasonably follows that this increased usage will pose a greater likelihood of interference to C-V2X Direct. Interference analyses that ignore this reality effectively ask consumers to accept significant risk of harmful interference and missed critical safety alerts every time an unlicensed device operates in a moving vehicle. If the device operates with a high-activity factor in the lowest portion of the U-NII-5 band, the traveler's C-V2X safety service will be negatively impacted.

In light of 5GAA's previous testing results and this latest analysis, the 5GAA representatives requested additional safeguards to mitigate the impact of portable VLP and mobile operations in the U-NII-5 band at a -27 dBm/MHz rms OOBE level.[17] The 5GAA representatives further noted other potential means of protecting C-V2X safety services that could be explored via a further notice of proposed rulemaking.[18]

Pursuant to the Commission's rules, this notice is being filed in the above-referenced docket for inclusion in the public record. Please contact me should you have any questions.

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[15] As 5GAA previously has suggested, if interference analyses are based on a low activity factor, the Commission should adopt a duty cycle limit for U-NII-5 devices that reflects the assumed activity factor upon which these analyses are based. *See* 5GAA Comments at n.15.

[16] *See, e.g.*, Letter from Apple Inc. et al., to Marlene H. Dortch, Secretary, Federal Communications Commission, ET Docket No. 18-295 & GN Docket No. 17-183, at 2 (filed Oct. 6, 2020) ("Wearable, in-vehicle, personal area network, and AR/VR are the key anticipated VLP use cases likely to drive the demand for VLP devices.").

[17] *See* 5GAA Presentation at 7.

[18] *See id.*

Sincerely,

/s/ Sean T. Conway
Sean T. Conway

Counsel to the 5G Automotive Association

cc: Meeting participants

Attachments

Attachment 1

CAMP LLC

Cellular V2X Device-to-Device Communication Consortium

CELLULAR V2X DEVICE-TO-DEVICE COMMUNICATION CONSORTIUM

C-V2X Performance Assessment Project

Task 8: Assessment of Wi-Fi Interference to C-V2X Communication Based on Proposed FCC 5.9 GHz NPRM

Interference Field Testing Results

9/28/2020

List of Acronyms

Abbreviation	Explanation	Abbreviation	Explanation
SEM	Spectral Emissions Mask	HP VA	High Power Variable Attenuator
OOBE	Out of Band Emissions	RMS	Root Mean Square
C-V2X	Cellular Vehicle to Everything	MCS	Modulation and Coding Scheme
U-NII-4	Unlicensed National Information Infrastructure (U-NII) radio band (5850 MHz -5895 MHz) proposed by the FCC NPRM	HARQ	Hybrid Automatic Repeat Request
ITS	Intelligent Transportation Systems	NPRM	Notice of Proposed Rule Making
3GPP	3G Partnership Project	LOS/NLOS	Line of Sight/Non-Line of Sight
VA	Variable Attenuator	V2X	Vehicle to Everything (X) where X can be Vehicle (V), Infrastructure (I) or Network (N)
TX	Transmitter	EIRP	Effective Isotropic Radiated Power
RX	Receiver	FCC	Federal Communications Commission
ACP	Average Carrier Power	PER	Packet Error Rate
CCDF	Complementary Cumulative Distribution Function	DNPW	Do Not Pass Warning
WFA	Wi-Fi Alliance	EEBL	Emergency Electronic Brake Light
AP	Access Point		

Executive Summary

- Wi-Fi Alliance proposed U-NII-4 OOBE limits for outdoor devices in their March, 2020 Comments to the 5.9 GHz NPRM
- CAMP C-V2X Consortium has field tested this proposal assuming an in-vehicle U-NII-4 interferer
  - Three (3) use cases with NLOS propagation conditions assumed
- Significant harmful interference to V2V and I2V safety communication was measured for all cases
- For this reason CAMP C-V2X Consortium strongly believes that the devices adhering to this OOBE mask should be:
  - Restricted to indoor only Wi-Fi Access Points (APs)
  - Prohibited to operate as portable Wi-Fi APs (that could be used in-vehicle)
- NOTE: Other proposals for OOBE limits of unlicensed devices are less stringent than used in this evaluation and, based on the results presented here, will cause additional harmful interference

Task 8: Technical Scope

- Evaluate the interference from Wi-Fi operations in the U-NII-4 band to C-V2X (3GPP Rel-14, mode 4) safety communications on Channel 180 and Channel 183 based on proposed rules in the January 2020 FCC 5.9GHz NPRM

- Period of Performance: February 01, 2020 – September 30, 2020

CH 180 : 5895 MHz – 5905 MHz
CH 183 : 5905 MHz – 5925 MHz
U-NII-4 (proposed) : 5850 MHz – 5895 MHz

Objective Test Description

Aimed at understanding Wi-Fi interference to C-V2X system performance in CH 180 and CH 183 under these system factors:

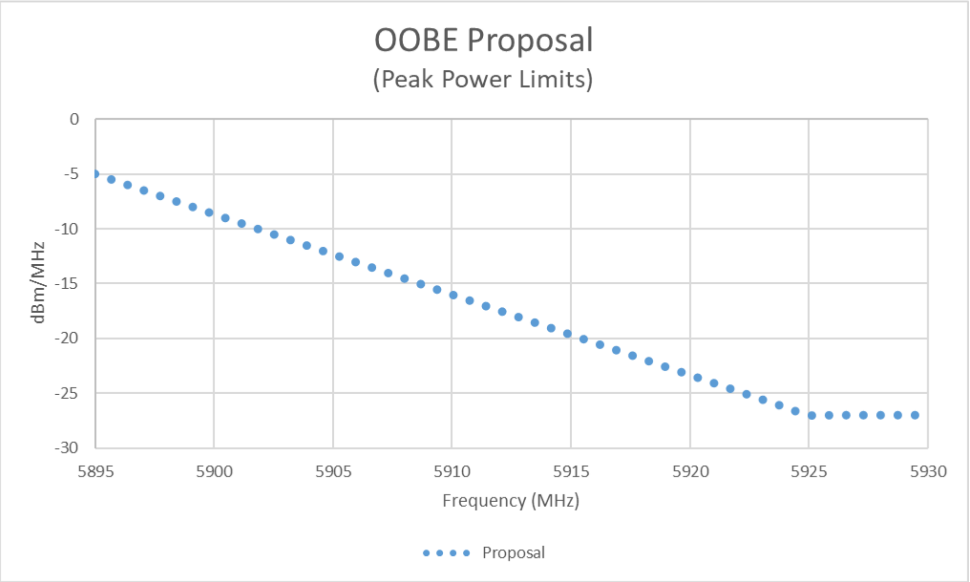
- C-V2X Device Configurations
  - Channel bandwidth – 10 MHz (CH 180) and 20 MHz (CH 183)
  - Payload size
    - 365 byte, supporting V2V messages
    - 1400 byte, supporting I2V messages

    Implemented as per SAE J3161
- Wi-Fi Alliance OOBE March Proposal in the FCC 5.9 GHz NPRM Docket[1]
- Wi-Fi Configurations
  - In-vehicle hotspot
  - Primary focus: 80 MHz (CH 171) Bandwidth Wi-Fi 802.11ac signal

[1] https://www.fcc.gov/ecfs/filing/1030974615271

Wi-Fi Alliance U-NII-4 OOBE Proposal

- Wi-Fi Alliance OOBE mask definition [1]
  - Linearly drawn to match peak power limit of
    - -5 dBm/MHz at 5895 MHz
    - −27 dBm/MHz >= 5925 MHz
  - Expressed in terms of EIRP
  - Applies outdoors



Note: A proposals in [2] for indoor-only usage OOBE limits would include building losses, offering additional protection to CH180 & CH183 transmissions.

[1] https://ecfsapi.fcc.gov/file/1030974615271
[2] https://ecfsapi.fcc.gov/file/10309096401111/5GAA%20Comments%20(3-9-2020).pdf

Test Setup

Test Scenarios

Scenario	Link Test
Non-line of Sight (NLOS)	V2V, I2V
NLOS Intersection	V2V

Test Configurations

Config Item	Values
Payload	365 Byte (V2V) 1400 Byte (I2V)
Antenna Diversity	2 Rx
HARQ	ON
C-V2X Channels	180, 183
Transmit Power	17dBm (at the antenna input) Note: Device configured for 20 dB Tx power with additional ~3dB cable loss and ~0dB antenna gain at Horizon
Inter-Transmit Time	100 ms
Wi-Fi AP	In-vehicle
Wi-Fi Antenna Gain	6 dBi
Wi-Fi Channel	171
C-V2X Antenna Conf	Roof-mounted Side-view Mirror

Interference Equipment

Device	Model
Signal Generator	Rohde & Schwarz | Model: SMBV100A
Bi-Directional Amplifier	Triad TTRM4302-D04
Signal Analyzer	Keysight or Agilent | Model: N9020A

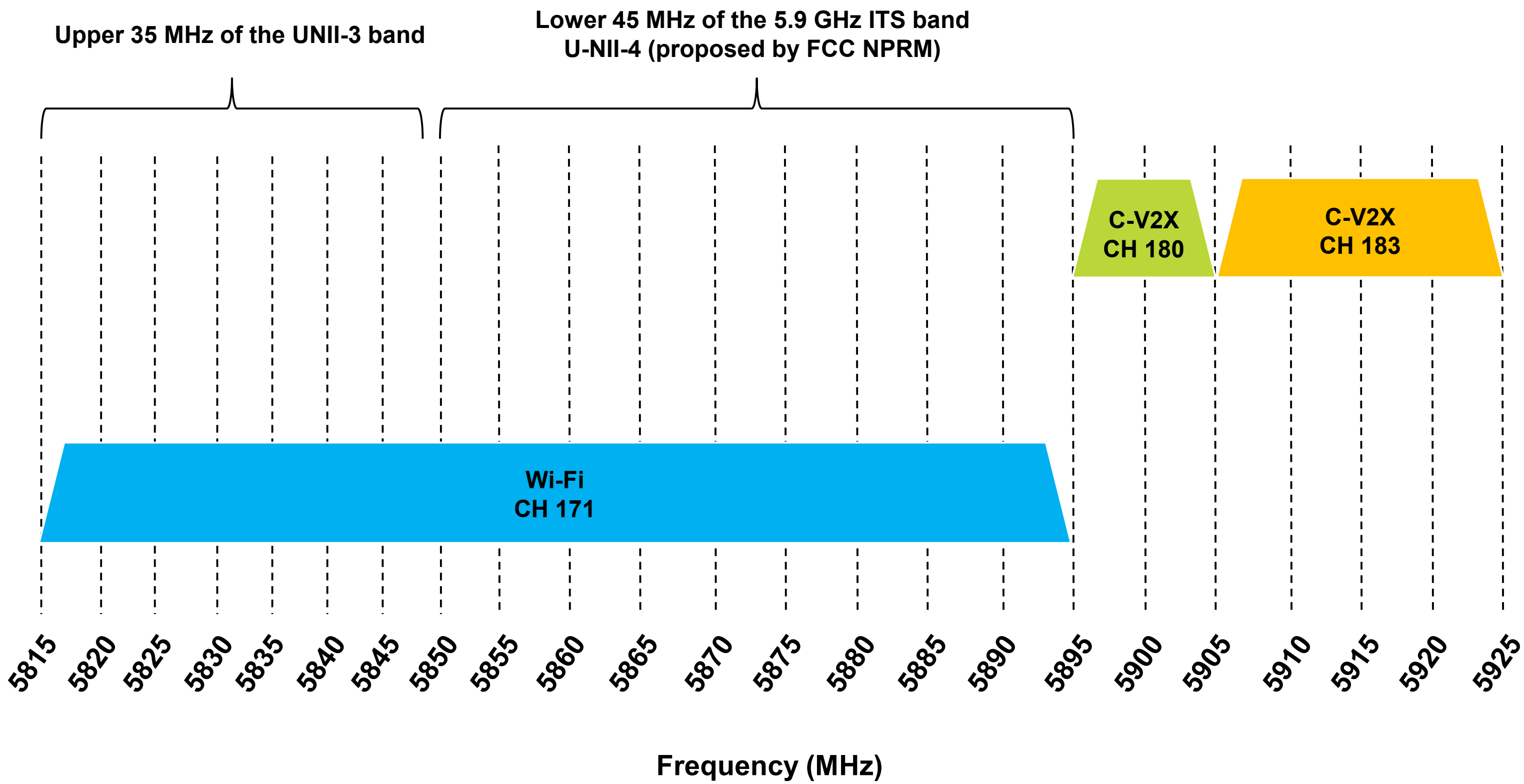
Others

Item	Value
Moving Vehicle Speed	25 MPH
Runtime / Test	6 Loops
Blocker Vehicle	26 ft truck

OBE-vehicle Mapping

OBE ID	Vehicle/ RSU
21	Nissan Pathfinder (OBE#31 used for 2 tests)
42	Nissan Rogue (OBE#32 used for 2 tests)
105	RSU w/ ECO6-5900-RN (6 dBi gain Antenna @ 18 ft)

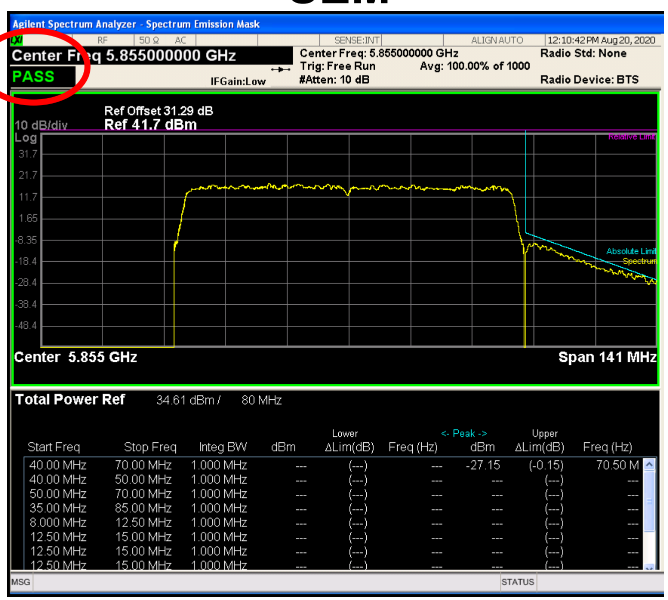
Wi-Fi and C-V2X Channels Used



Generated 802.11ac Waveform, CH 171 (80 MHz) – Wi-Fi Alliance Proposal Mask | In-vehicle Hotspot

- Spectral Emission Mask (SEM): used to confirm that the Out of Band Emissions (OOBE) of the generated waveform is met
- Average Carrier Power (ACP): used to measure the level of OOBE in the adjacent channel
- Antenna Gain (6 dBi) and cable loss (3.1 dB) of the interferer setup included as offsets in measurements and accounted for

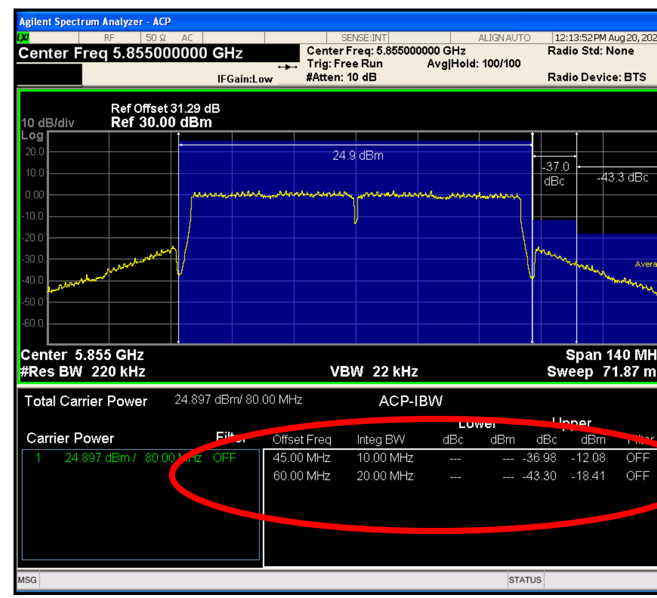
SEM



Total Power Ref 34.61 dBm / 80 MHz

Key Settings: Res BW: 1 MHz, Max Hold, Peak Detector

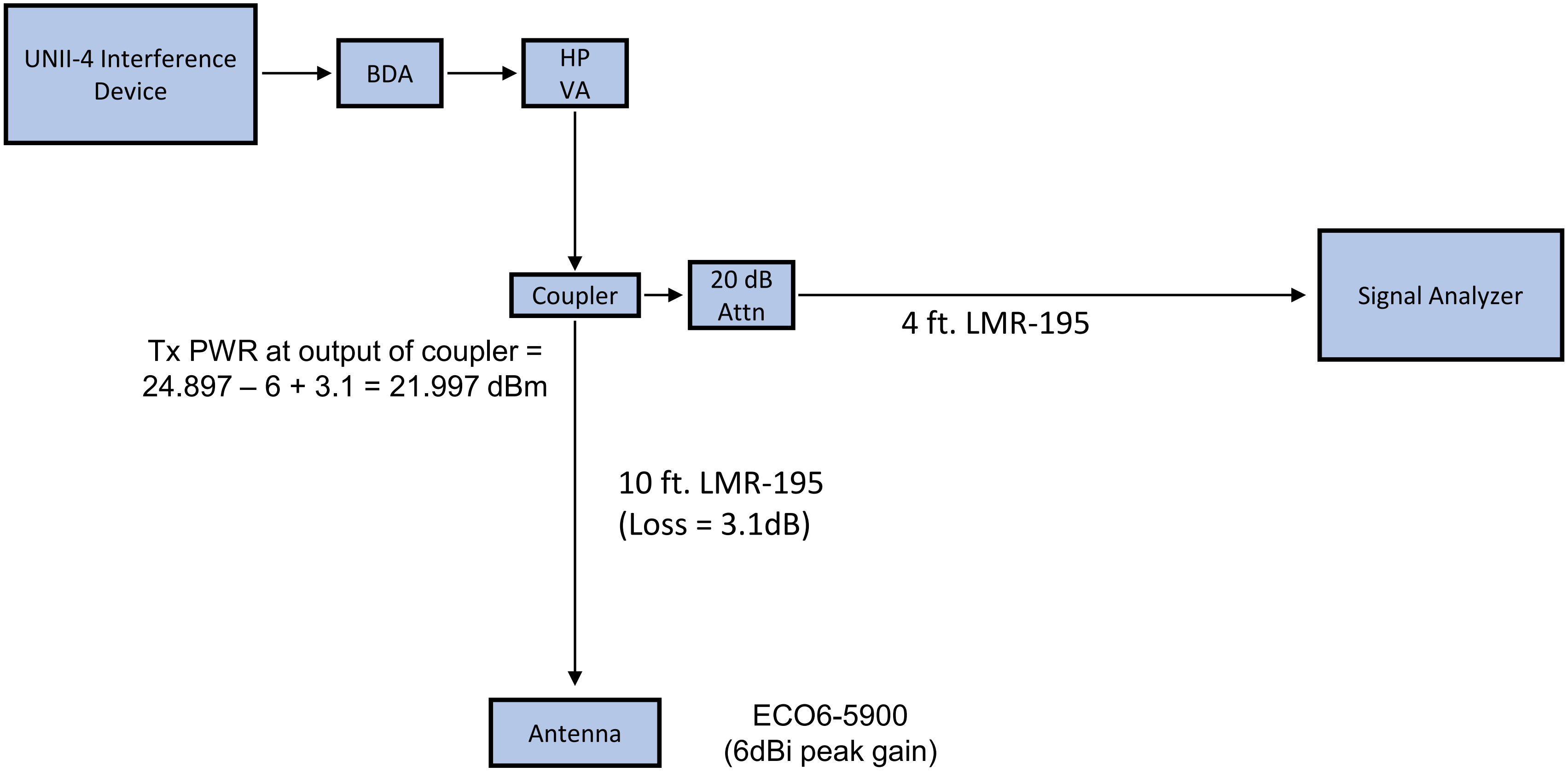
ACP



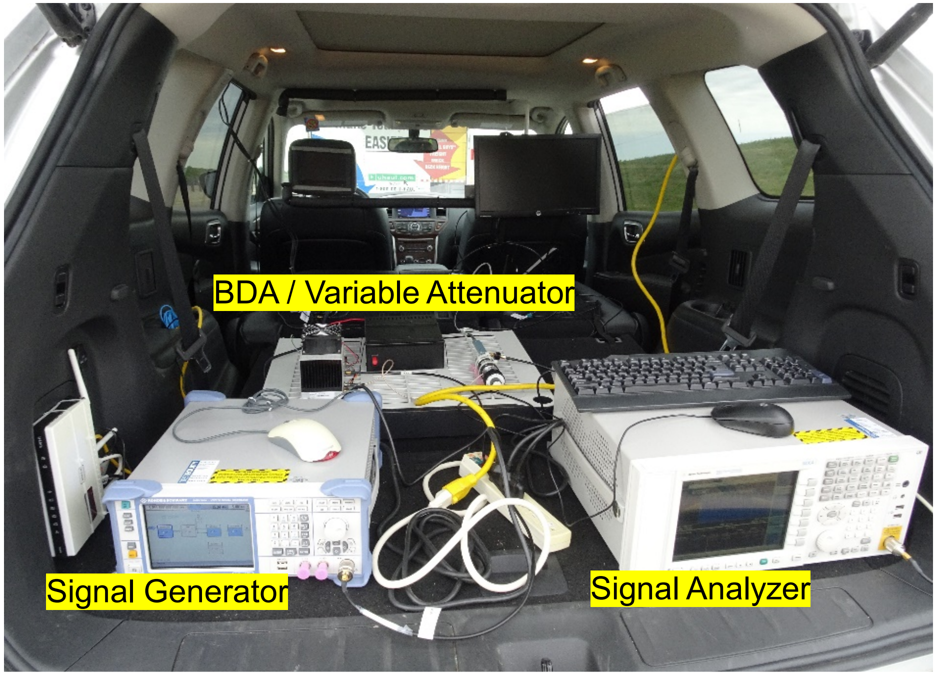
Total Carrier Power 24.897 dBm / 80 MHz

Key Settings: Avg Detector, RMS Avg

Interferer Setup



In-vehicle Hotspot Setup

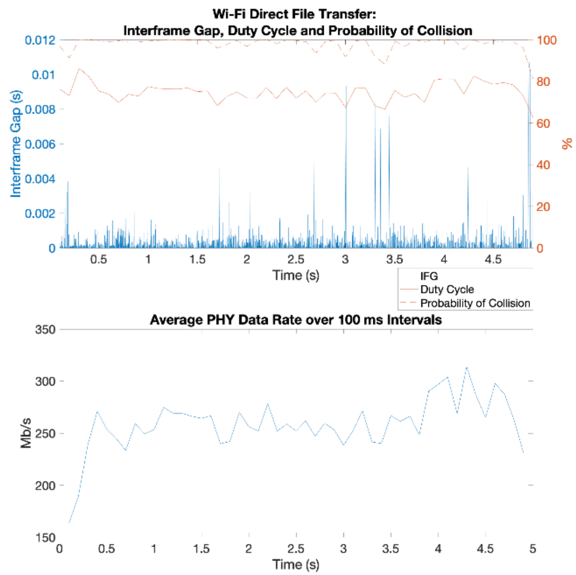


- Wi-Fi Interference Source - Signal Generator with Generated 802.11ac waveform
- Duty cycle was set at 60%
- 80 MHz (CH 171) waveform complied with the Wi-Fi Alliance proposal mask
- The Wi-Fi antenna was placed on the front passenger seat
- This placement approximates a passenger holding a mobile device

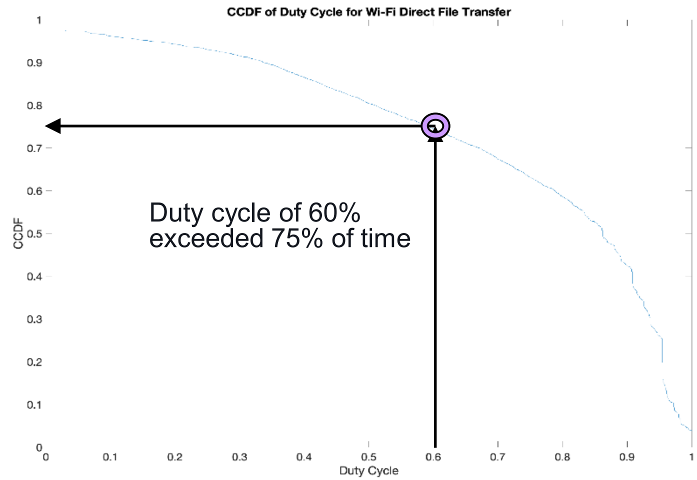
Interference Duty Cycle Comparison to Sniffed Wi-Fi Activity

- The duty cycle of the Wi-Fi signal in the field tests was set at 60% which is not the worst case
- In the peer-to-peer direct file transfer test reported in [3] the average duty cycle was above 75% measured over 100 ms periods
- Duty cycle measurement over periods that last minutes, as reported in other studies, does not provide accurate information to assess harmful interference in collision scenarios

Interframe gap, duty cycle, probability of collision, data rate



Duty Cycle CCDF

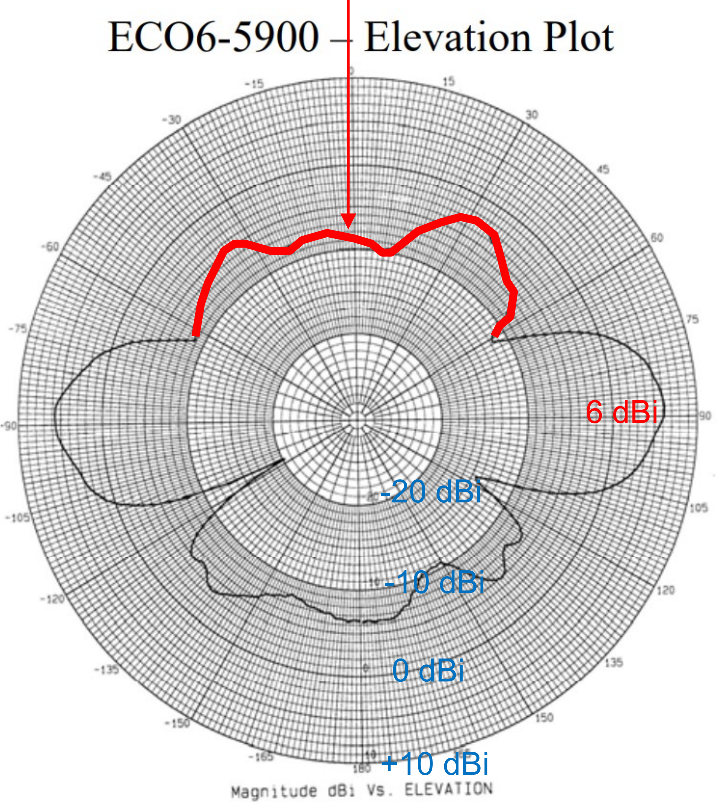


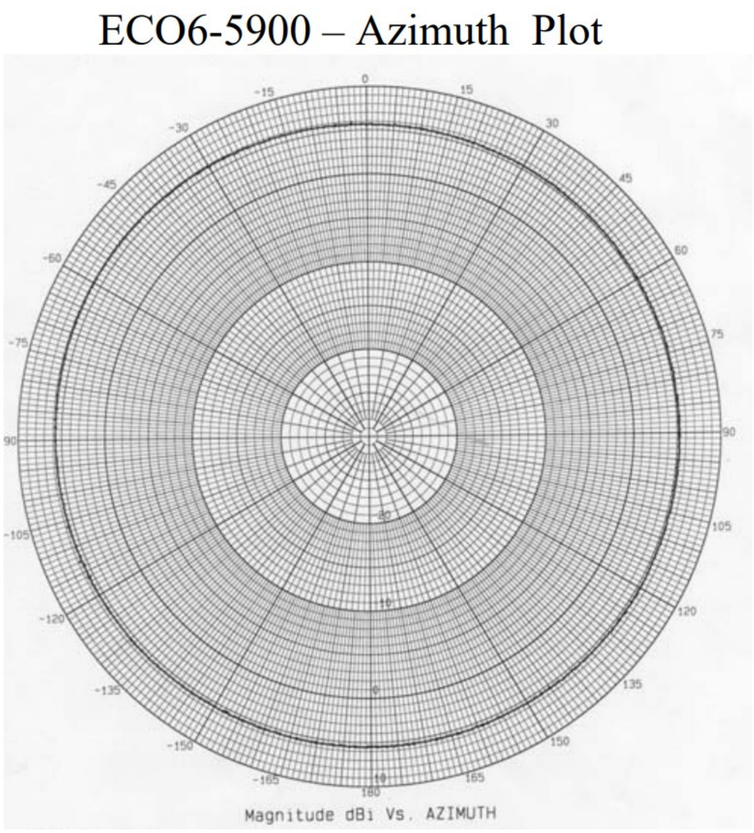
[3] https://ecfsapi.fcc.gov/file/1042725827205/Ford%20Motor%20Company%205.9%20GHz%20FCC%20Reply%20Comments%20as%20Filed%204-27-20.pdf

Wi-Fi Antenna Pattern (ECO6-5900)

Given the position of the antenna the average gain in the elevation toward the roof of the car is approximately -7 dBi

Given this antenna emission pattern, this set-up is estimated to provide ~13 dB of isolation between the Wi-Fi and C-V2X antennas – this implies that resulting interference could be worse than observed when smaller gain, more omni-directional antennas are used.

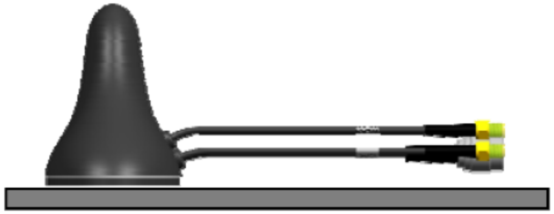




[4] https://www.mobilemark.com/wp-admin/admin-ajax.php?juwpfisadmin=false&action=wpfd&task=file.download&wpfd_category_id=2014&wpfd_file_id=6589&token=13fbaaa1df6f6e0b3daa4b4fcf9d31e7&preview=1

Vehicle Radiated RF Power

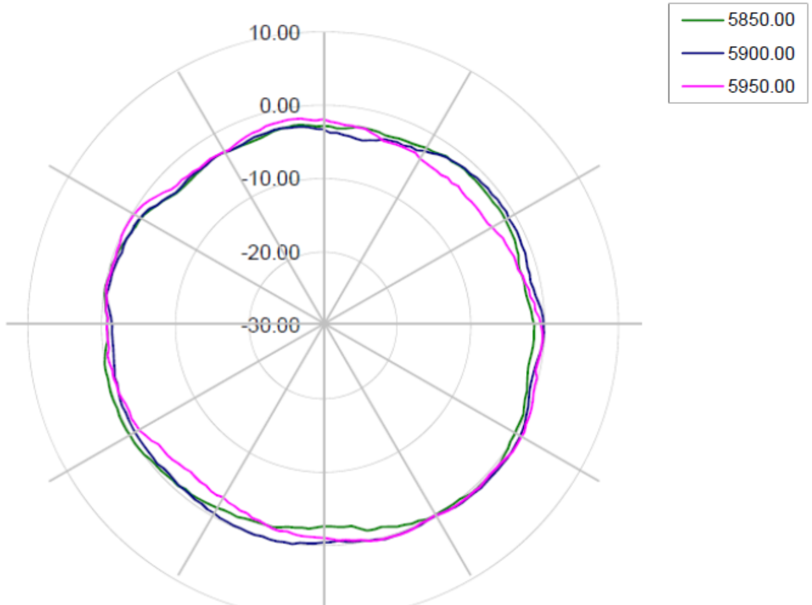
Radiated Power = Antenna Gain + Tx Power (unit) – Cable Loss
Tx Power (unit) = 20 dBm
Cable Loss (LMR 200, 3 meters) = ~ 3 dB
Antenna gain (horizon) = ~ 0 dBi
Radiated Power = ~ 17 dBm



Sketch #2—Mount on surface

Magnet Mount Antenna

Radiation Pattern @ 5.85 GHz, 5.90 GHz, 5.95 GHz



Pattern #1—90 degree elevation

The scale on the patterns is gain in dBi

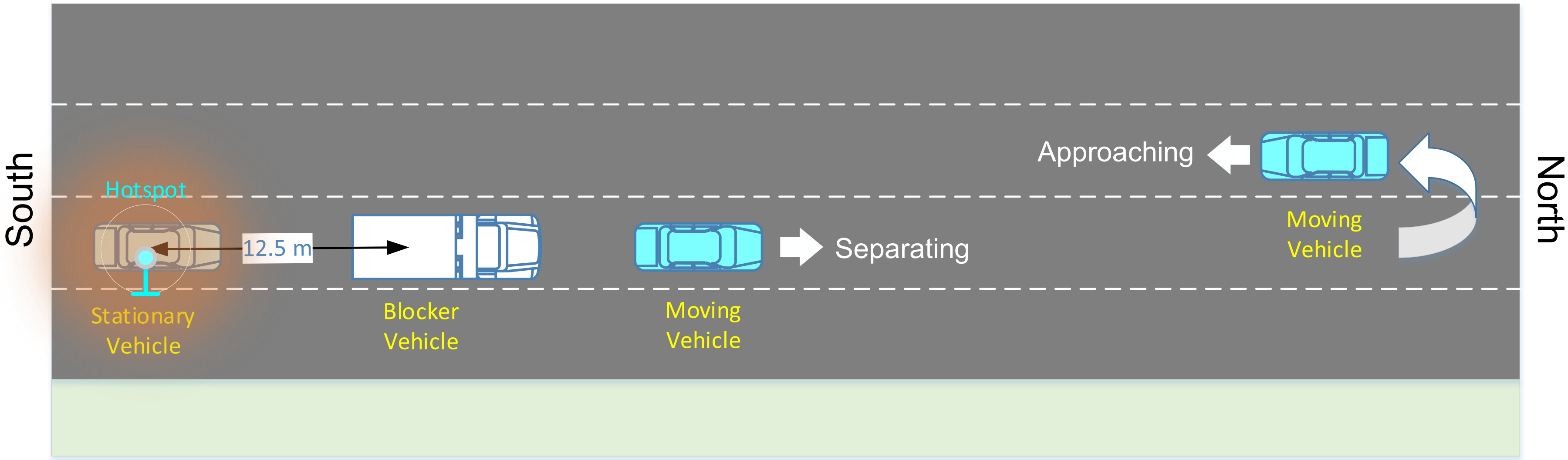
These patterns were measured on a 1m diameter circular ground plane with the antenna in the center

V2V Non-line of Sight (NLOS)

Test Setup: V2V NLOS

Primary Rx (Stationary) → 21 [Nissan Pathfinder]
Primary Tx (Moving) → 42 [Nissan Rogue]

In-vehicle Hotspot



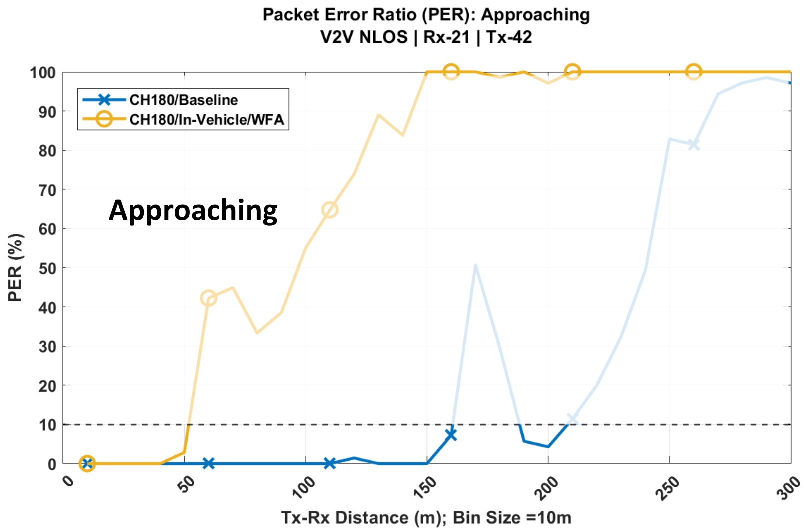
Roof-mounted C-V2X Antenna Setup

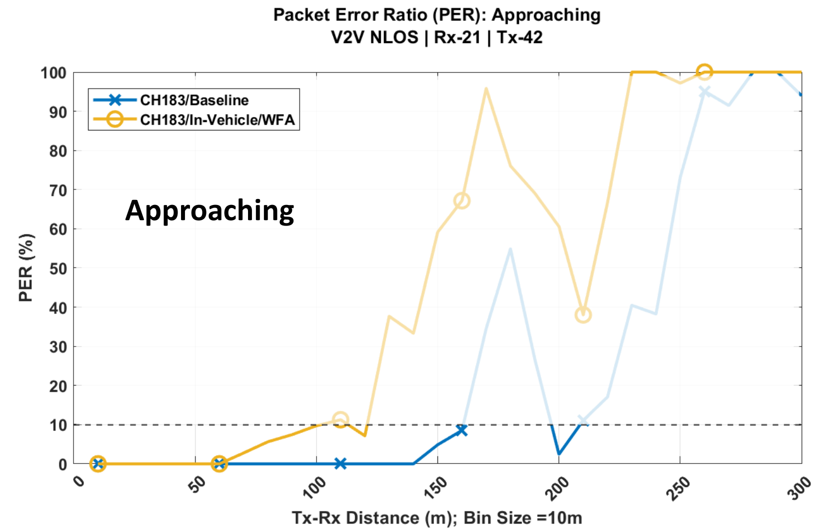
- The isolation between the in-vehicle hotspot and the primary and secondary V2X antennas was measured at 56 dB and 64 dB, respectively

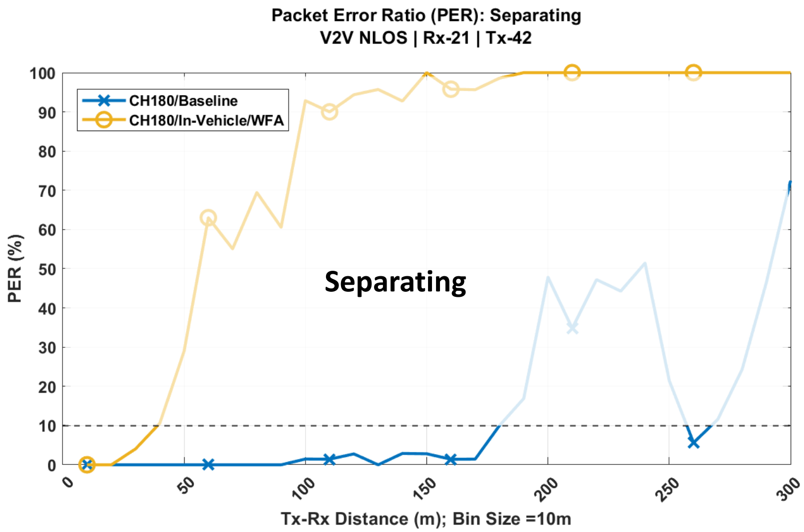
V2V NLOS (Roof-mounted C-V2X Antenna)

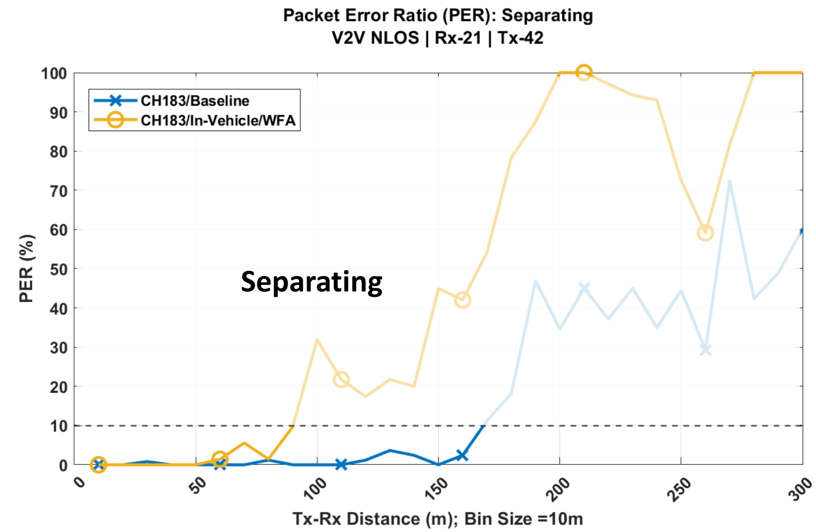
Stationary Vehicle Receiving

CH 180	CH 183









Impact on Safety Applications in CH 183

Test	Safety App	Warning Distance (10% PER) (m) w/o and w/ Wi-Fi	No Wi-Fi Maximum Safe Relative Speed (mph)	Wi-Fi Active Maximum Safe Relative Speed (mph)
V2V NLOS (approaching)	DNPW	160/110	45	31
V2V NLOS (separating)	EEBL	160/80	68	45

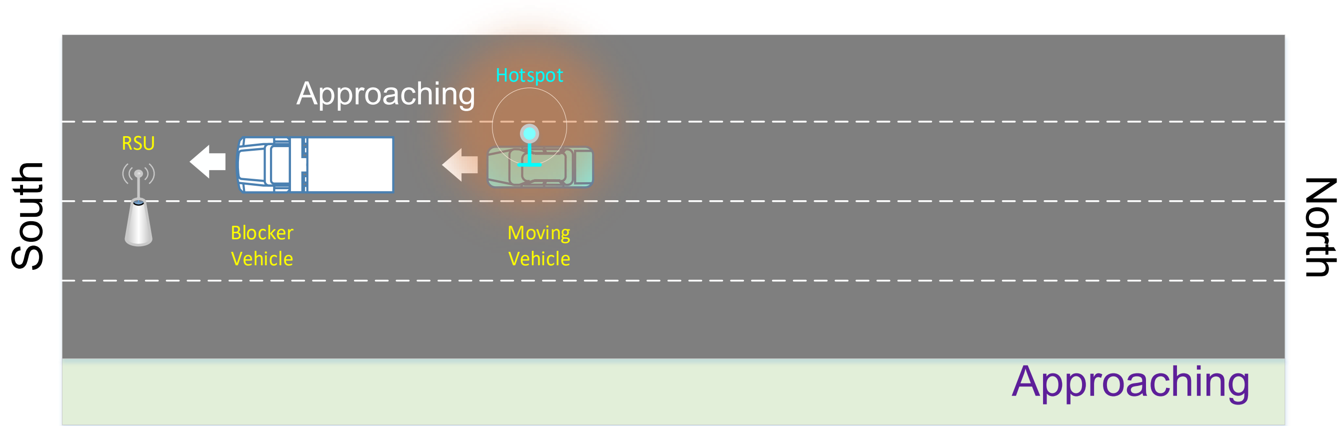
- Vehicles emulate Do Not Pass Warning (DNPW) Scenario while approaching and emulating the Electronic Emergency Brake Light (EEBL) Scenario while separating
- DNPW: Assuming 8 second margin between safe cross-over between north-bound and south-bound vehicles
- EEBL: Truck suddenly changes lane late and with 1.5s driver reaction, rear vehicle decelerates at 4 ms^{-2} just before vehicle in the front that is assumed stopped
- In both cases, the presence of Wi-Fi interference causes reduction in safe relative speed

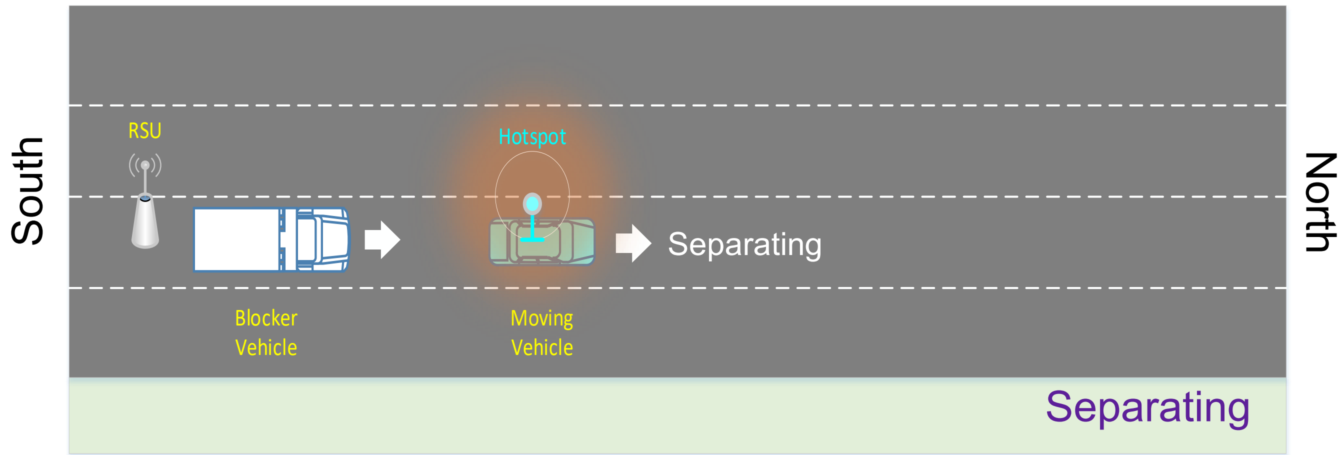
I2V Non-line of Sight (NLOS)

Test Setup: I2V NLOS

In-vehicle Hotspot

Primary Rx (Moving) → 21 [Nissan Pathfinder]
Primary Tx (Stationary) → 105 [RSU]



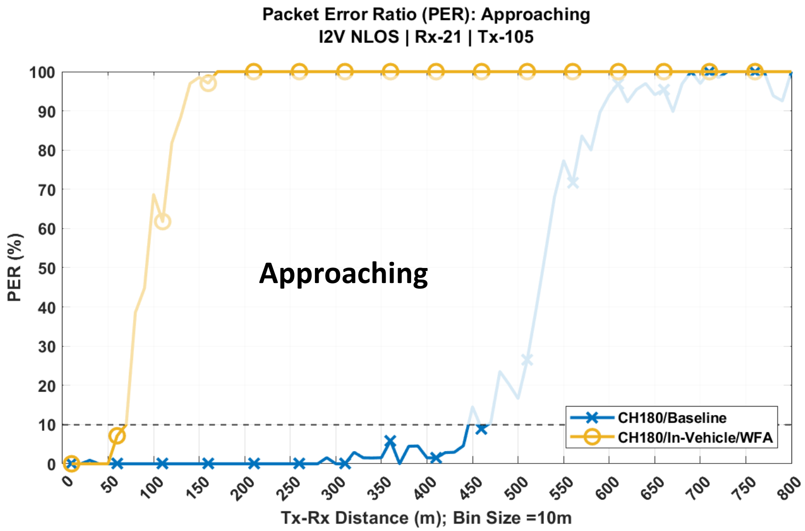


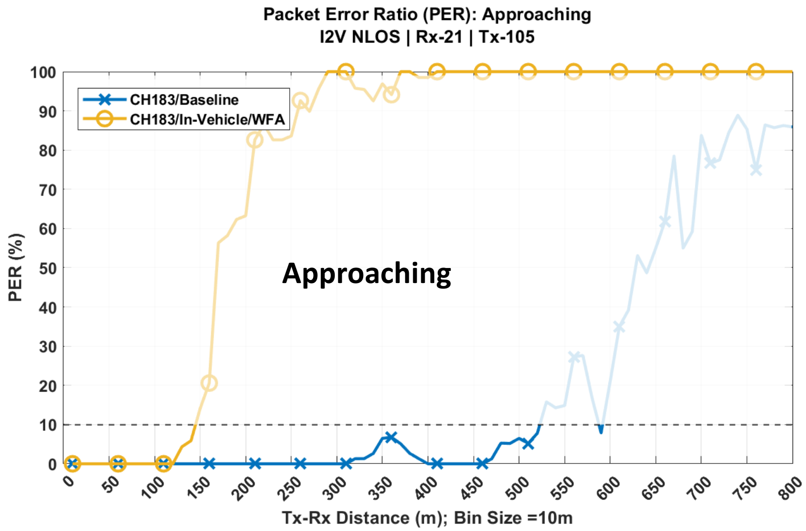
I2V NLOS (Roof-mounted C-V2X Antenna)

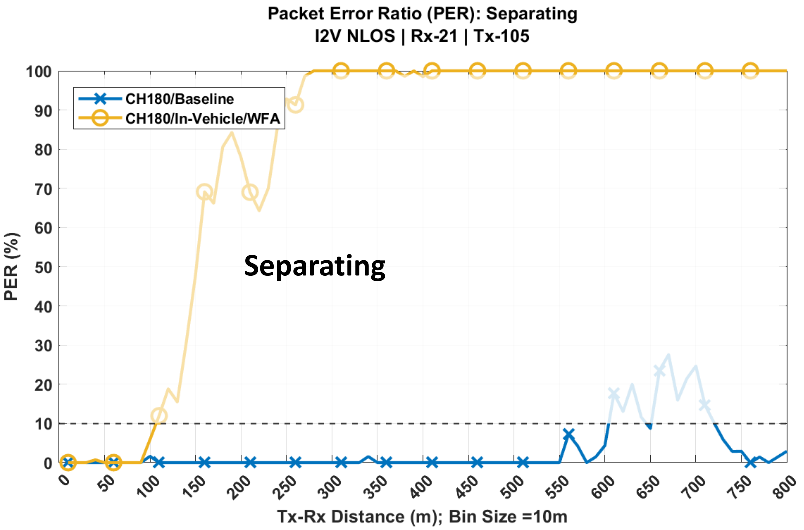
Moving Vehicle Receiving From RSU

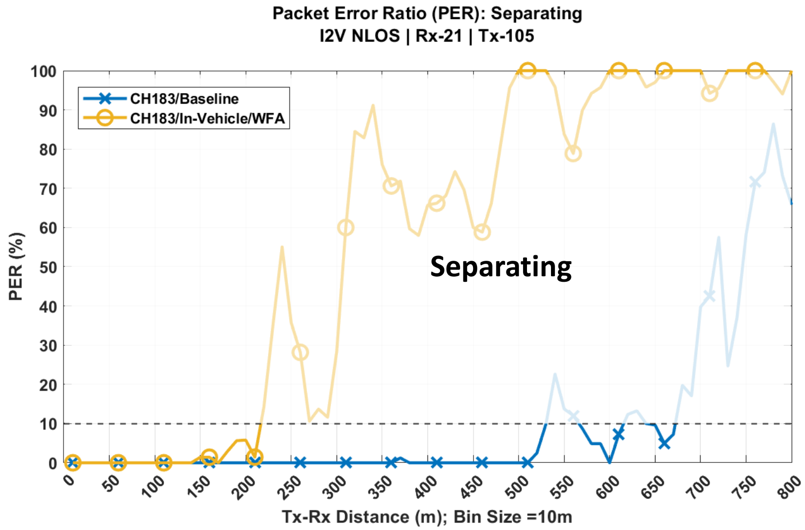
CH 180

CH 183







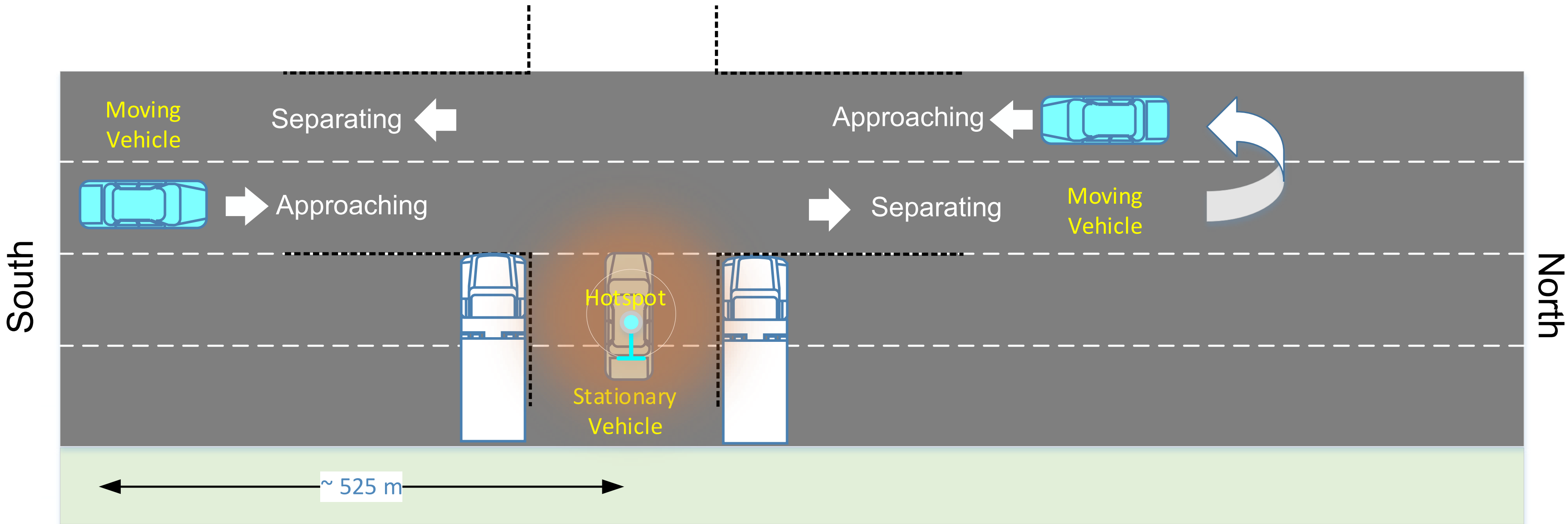


V2V NLOS Intersection

Test Setup: V2V NLOS Intersection

In-vehicle Hotspot

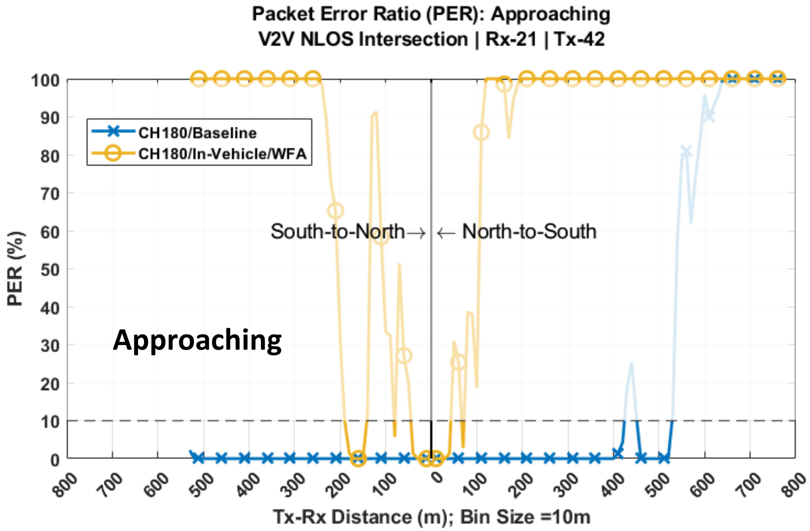
Primary Rx (Stationary) → 21 [Nissan Pathfinder]
Primary Tx (Moving) → 42 [Nissan Rogue]

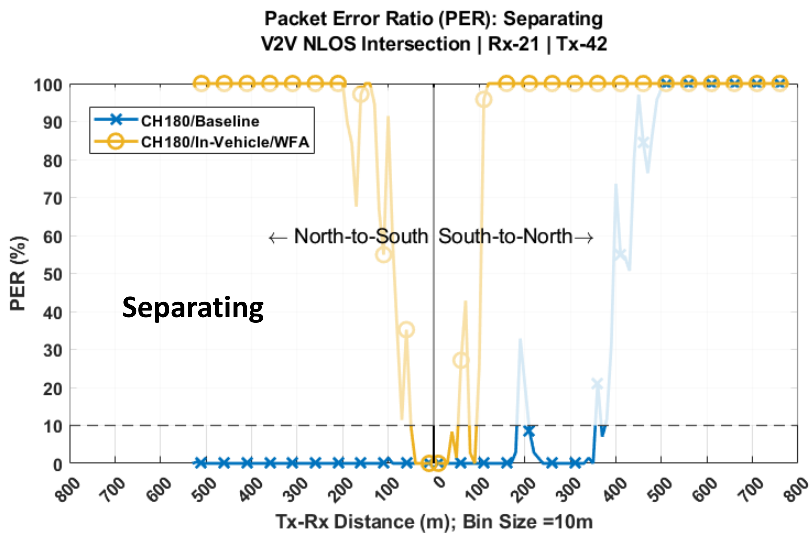


V2V NLOS Intersection (Roof-mounted C-V2X Antenna)

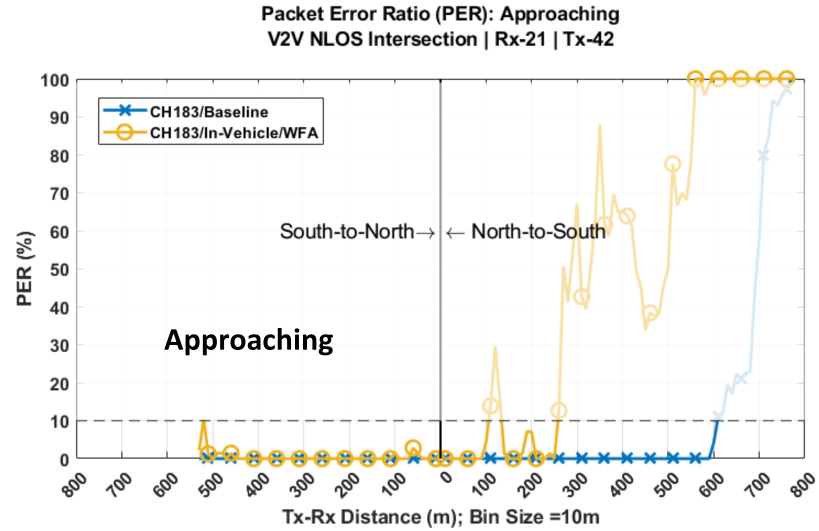
Stationary Vehicle Receiving

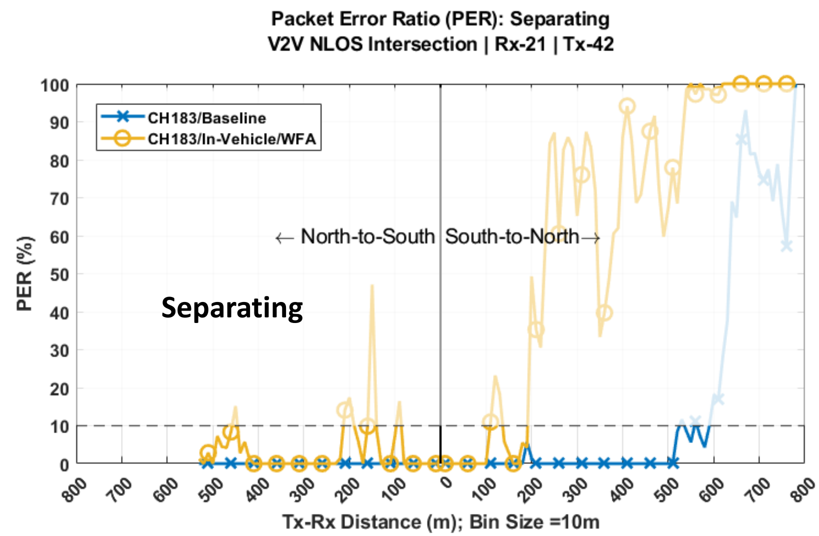
CH 180





CH 183



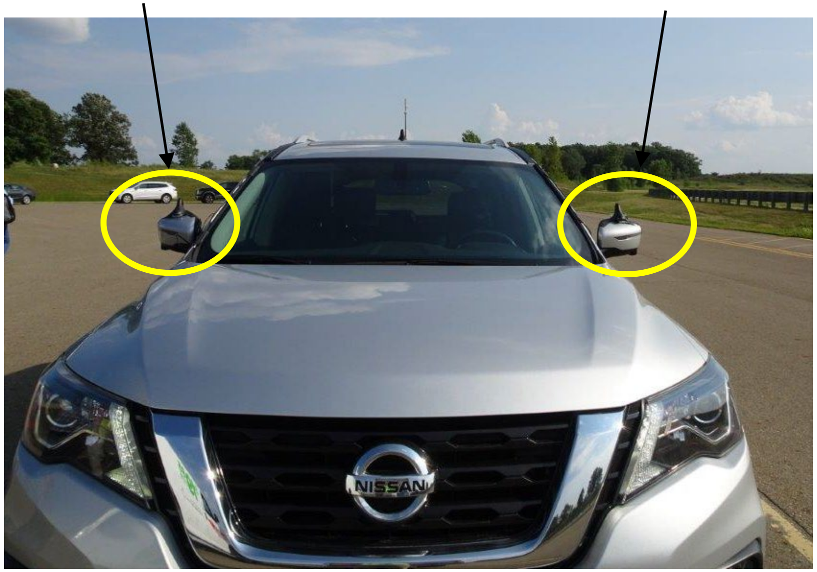


Testing Summary – In-vehicle Hotspot (Roof-mounted C-V2X Antenna)

Communication Range (@ PER < 10%)								
	Approaching				Separating			
TEST SCENARIOS	CH 180		CH 183		CH 180		CH 183	
	No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot
V2V NLOS	160 m	50 m	160 m	100 m	180 m	40 m	170 m	90 m
I2V NLOS	440 m	70 m	520 m	150 m	600 m	110 m	530 m	220 m
V2V NLOS Intersection	420 m	40 m	610 m	110 m	380 m	50 m	590 m	190 m

- Significant communication range degradation in the presence of U-NII-4 Wi-Fi in-vehicle Hotspot
- Both CH 180 and CH 183 are impacted, with higher harmful impact on CH 180

Side-mirror C-V2X Antenna Setup

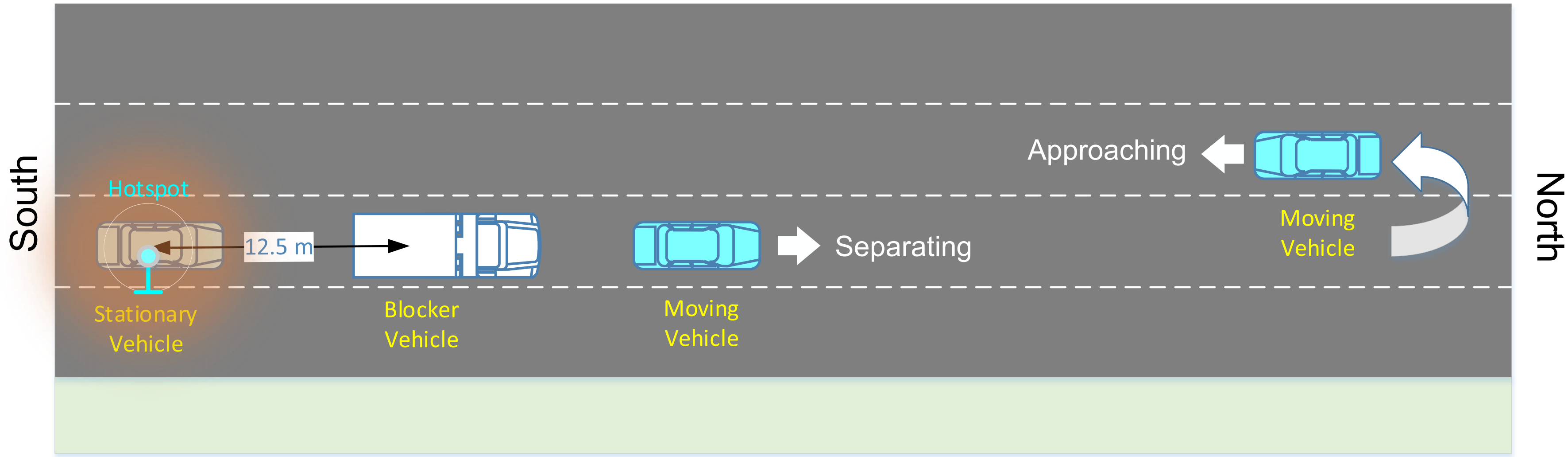


- Side-mirror C-V2X antennas were placed only on the stationary vehicle
  - Moving vehicle still had roof-mounted C-V2X antennas
- The isolation between the in-vehicle hotspot and the primary and secondary V2X antennas was measured at 52 dB and 60 dB, respectively

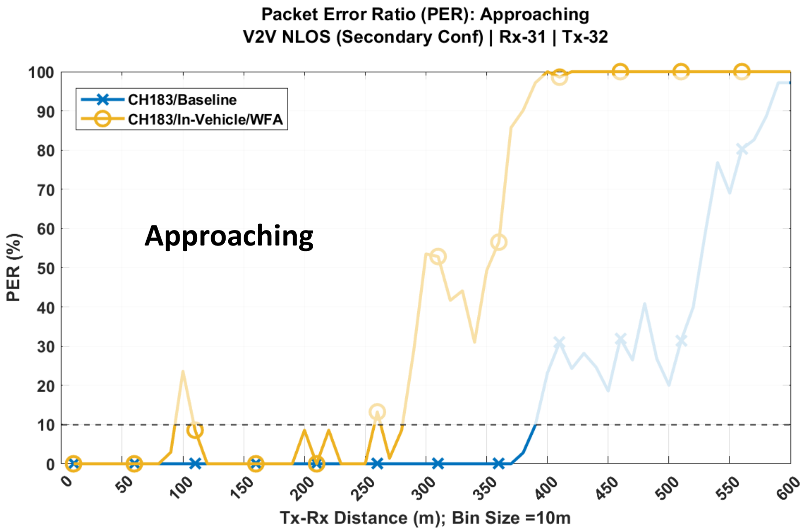
Test Setup: V2V NLOS

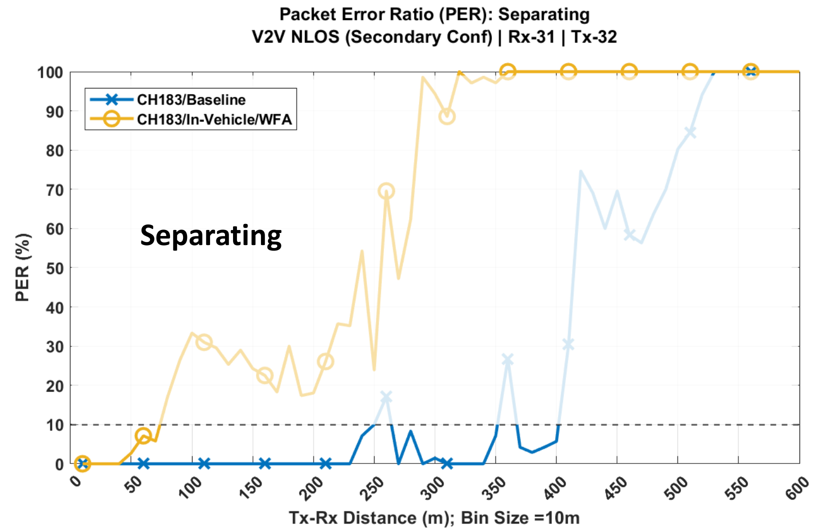
Primary Rx (Stationary) → 21 [Nissan Pathfinder]
Primary Tx (Moving) → 42 [Nissan Rogue]

In-vehicle Hotspot



V2V NLOS (Side-mirror C-V2X Antenna)
Stationary Vehicle Receiving
CH 183





Testing Summary – In-vehicle Hotspot (Side-mirror C-V2X Antenna)

Communication Range (@ PER < 10%)			
Approaching		Separating	
No Wi-Fi	In-vehicle Hotspot	No Wi-Fi	In-vehicle Hotspot
390 m	100 m	400 m	70 m

- Side-mirror C-V2X antenna configuration is tested in V2V NLOS Scenario with the same placement of the in-vehicle Wi-Fi antenna as in the previous tests
  - Only CH 183 was tested

- Significant communication range degradation in the presence of In-vehicle Hotspot U-NII-4 Wi-Fi operation

- With less spectral separation, interference to CH180 is expected to be greater than observed in CH183

Conclusions

- Field tests of three (3) V2X safety use cases have clearly shown harmful interference when U-NII-4 Wi-Fi devices operate in-vehicle
- Depending on the choice and positioning of the Wi-Fi antenna in-vehicle the interference to C-V2X can be even higher
- For that reason, additional protection of V2X safety applications is required

Backup

C-V2X Device Parameters

	20 MHz (CH 183)		10 MHz (CH 180)	
Packet Size	MCS	Num Sub Channels	MCS	Num Sub Channels
365	11	2	11	2
1400	7	10	7	5

Sub-Channel Size = 10 Resource Blocks (RB)
HARQ Enabled

Attachment 2

CAMP LLC

Cellular V2X Device-to-Device Communication Consortium

CELLULAR V2X DEVICE-TO-DEVICE COMMUNICATION CONSORTIUM

C-V2X Performance Assessment Project

Task 8: Assessment of WiFi Interference to C-V2X Communication Based on Proposed FCC 5.9 GHz NPRM

April 15, 2020

List of Acronyms

Abbreviation	
SEM	Spectral Emissions Mask
OOBE	Out of Band Emissions
C-V2X	Cellular Vehicle to Everything
U-NII-4	Unlicensed National Information Infrastructure (U-NII) radio band (5850 MHz -5895 MHz) proposed by the FCC NPRM
ITS	Intelligent Transportation Systems
3GPP	3G Partnership Project
VA	Variable Attenuator
TX	Transmitter
PRX	Primary Receive
DRX	Diversity Receive
HPA	High Power Variable Attenuator
RMS	Root Mean Square
MCS	Modulation and Coding Scheme
HARQ	Hybrid Automatic Repeat Request

Task 8: Technical Scope

- Evaluate the interference from Wi-Fi operations in the U-NII-4 band to C-V2X (3GPP Rel-14, mode 4) safety communications on Channel 180 and Channel 183 based on proposed rules in the January 2020 FCC 5.9GHz NPRM
- Period of Performance: February 01, 2020 – May 31, 2020

CH 180 : 5895 MHz – 5905 MHz
CH 183 : 5905 MHz – 5915 MHz
U-NII-4(proposed) : 5850 MHz – 5895 MHz

Task 8: Testing Categories

- Wi-Fi Interference Source Characterization - Completed
- Bench Testing - Completed
- Field Testing – V2V & V2I Scenarios – Not Started

Objective Test Description

Aimed at understanding Wi-Fi interference to C-V2X system performance in CH 180 and CH 183 under these system factors:

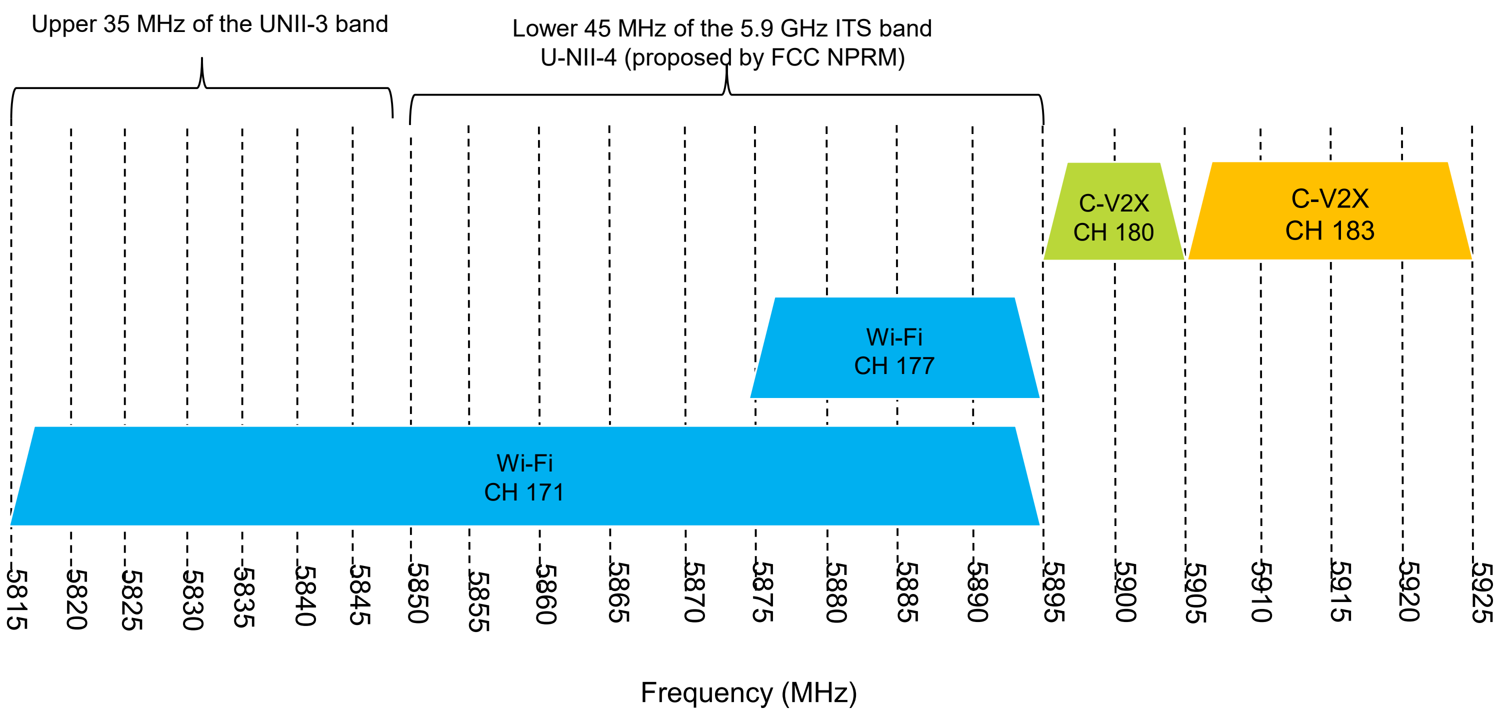
- C-V2X Device Parameters
  - Channel bandwidth – 10 MHz (CH 180) and 20 MHz (CH 183)
  - Sub-Channel Size 10 RBs
  - 365 byte, MCS 11, 2 sub-channels, supporting V2V messages
  - 1400 byte, MCS 7, 5 sub-channels (10 MHz BW) or 10 sub-channels (20 MHz BW), supporting I2V messages

- Wi-Fi OOBE Proposal Submissions to FCC Docket
  - Proposal 1 (Link , Outdoor Operation)
  - Proposal 2 (Link, Indoor Operation)

- Wi-Fi Parameters
  - 20 MHz (CH 177) and 80 MHz (CH 171) Bandwidth Wi-Fi 802.11ac signal

Proposal 1: https://www.fcc.gov/ecfs/filing/1030974615271
Proposal 2 : https://ecfsapi.fcc.gov/file/10309096401111/5GAA Comments (3-9-2020).

Wi-Fi and C-V2X Channels Used



C-V2X Device Parameters

	20 MHz (CH 183)		10 MHz (CH 180)	
Packet Size	MCS	Num Sub Channels	MCS	Num Sub Channels
365	11	2	11	2
1400	7	10	7	5

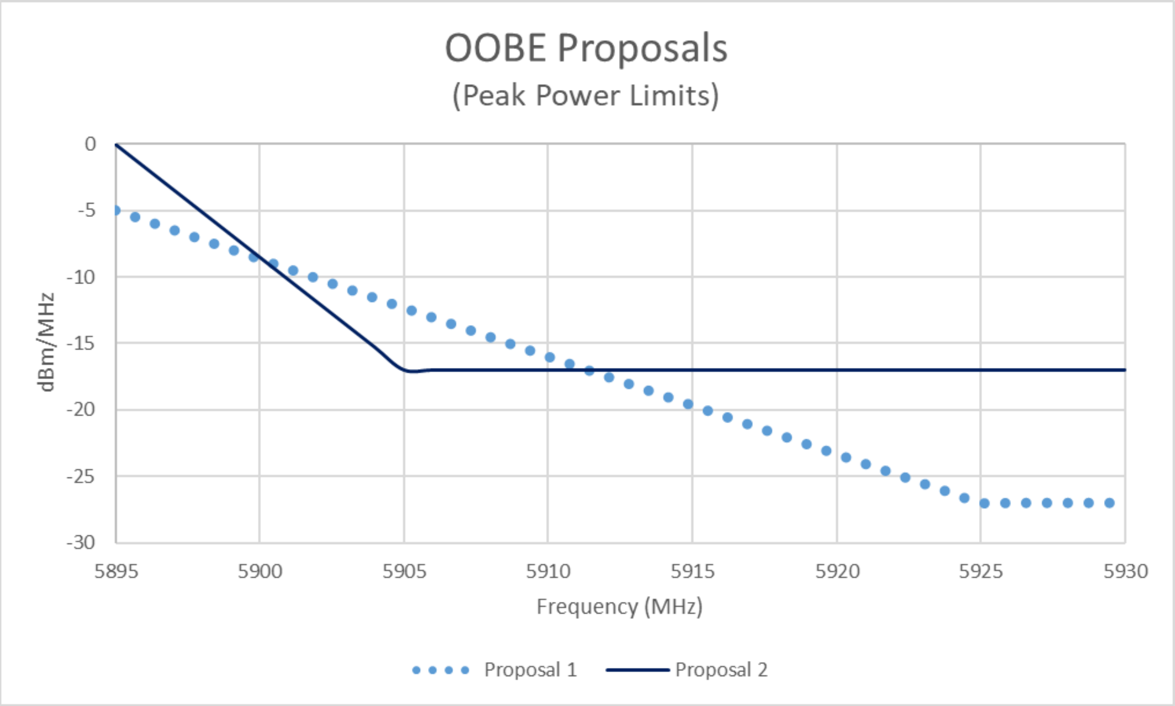
Sub-Channel Size = 10 Resource Blocks (RB)
HARQ Enabled

Note1: The parameters are subject to change pending future implementations and/or standards recommendations
Note2: Please see Appendix for C-V2X Device used for testing

Wi-Fi Interference OOBE Proposals

- Proposal 1 (Link)
  - Linearly drawn to match
    - -5 dBm/MHz at 5895 MHz
    - −27 dBm/MHz >= 5925 MHz
  - Outdoor Operation

- Proposal 2 (Link)
  - Linearly drawn to match
    - 0 dBm/MHz @ 5895 MHz
    - -17 dBm/MHz @ 5905 MHz
    - -17dBm/MHz > 5905 MHz
  - Indoor Operation



- Note
  - All Masks drawn for Peak Levels

Proposal 1: https://www.fcc.gov/ecfs/filing/1030974615271
Proposal 2 : https://ecfsapi.fcc.gov/file/10309096401111/5GAA Comments (3-9-2020).pdf

Wi-Fi Interference Sources

- 802.11ac U-NII-3 Devices Modified to work in U-NII-4 band
  - 20MHz U-NII-4 operation to asses impact to CH 180
    - Wi-Fi CH 177 (5875 MHz – 5895 MHz)
  - 80MHz U-NII-4 operation to assess impact to CH 183
    - Wi-Fi CH 171 (5815 MHz – 5895 MHz)

- Signal Generator with Generated 802.11ac waveform
  - Maximize OOBE to the extent possible under allowed proposals
    - 20 MHz (CH 177) waveform targeted for Proposal 2 mask
    - 80 MHz (CH 171) waveform targeted for Proposal 1 mask

Wi-Fi Interference Device Characterization

- Characterize OOBE emissions of the Wi-Fi interference sources w.r.t the OOBE proposals being considered. Namely:
  - Proposal 1
  - Proposal 2

- Characterize interference (rms power) in CH 180 and CH 183 from U-NII-4 operation for the different proposals

Interference Device Characterization Procedure

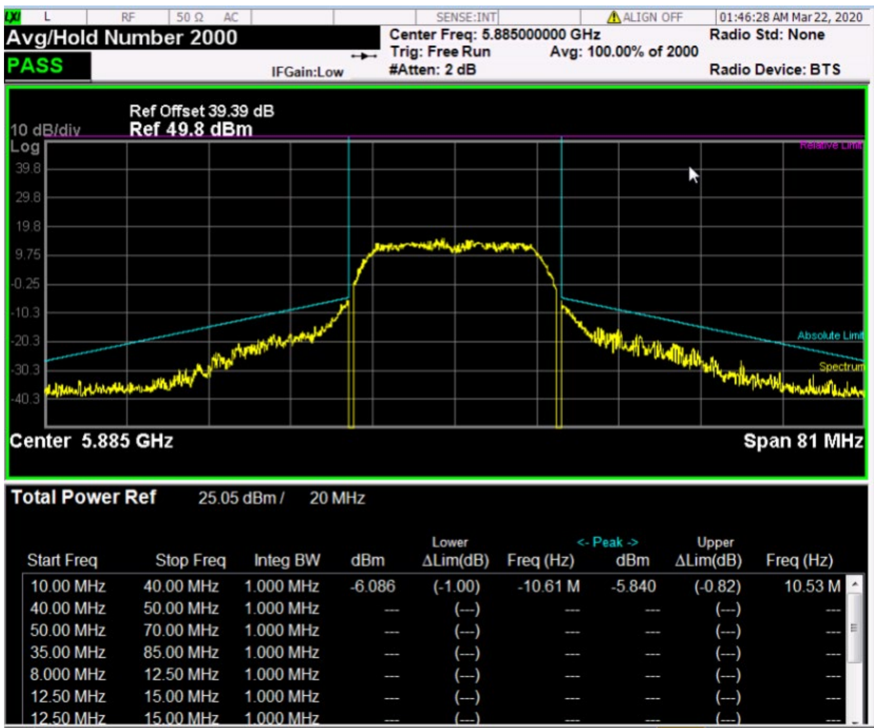
- Configure the interference device to comply with the OOBE proposal for each test
- Verify that the OOBE meet the Spectrum Emission Mask (SEM) on the spectrum analyzer (as per Slide 8)
  - In addition, setup the spectrum analyzer with the following key settings: Res BW: 1 MHz, Max Hold, Peak Detector, RF Burst Capture
- Set the Tx power of the interferer to maximum possible power while still meeting the SEM under test
- Note interference (rms power) in CH 180 and CH 183

Device Characterization

Wi-Fi Interferer	Wi-Fi BW (MHz)	OOBE Proposal
802.11ac Devices	20	Proposal 1 (Outdoor)
802.11ac Devices	80	Proposal 1 (Outdoor)
802.11ac Devices	20	Proposal 2 (Indoor)
802.11ac Devices	80	Proposal 2 (Indoor)
Generated 802.11ac Waveform	80	Proposal 1 (Outdoor)
Generated 802.11ac Waveform	20	Proposal 2 (Indoor)

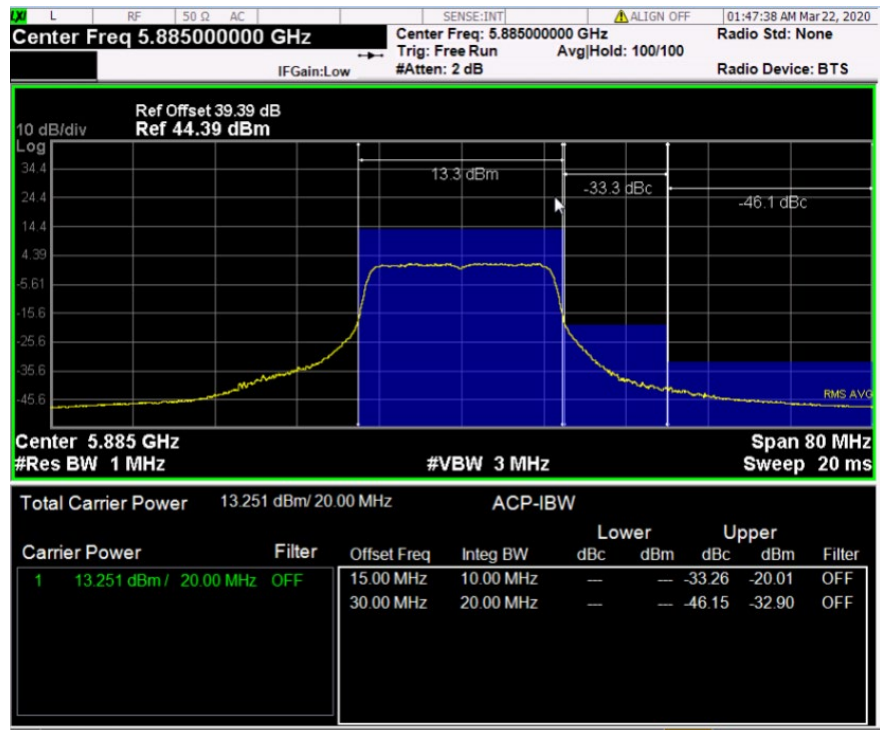
802.11ac Devices, CH 177 (20 MHz) – TX Power Adjusted to Meet Proposal 1 Mask

OOBE - Proposal 1 SEM (Proposed)



Key Settings: Res BW: 1 MHz, Max Hold, Peak Detector

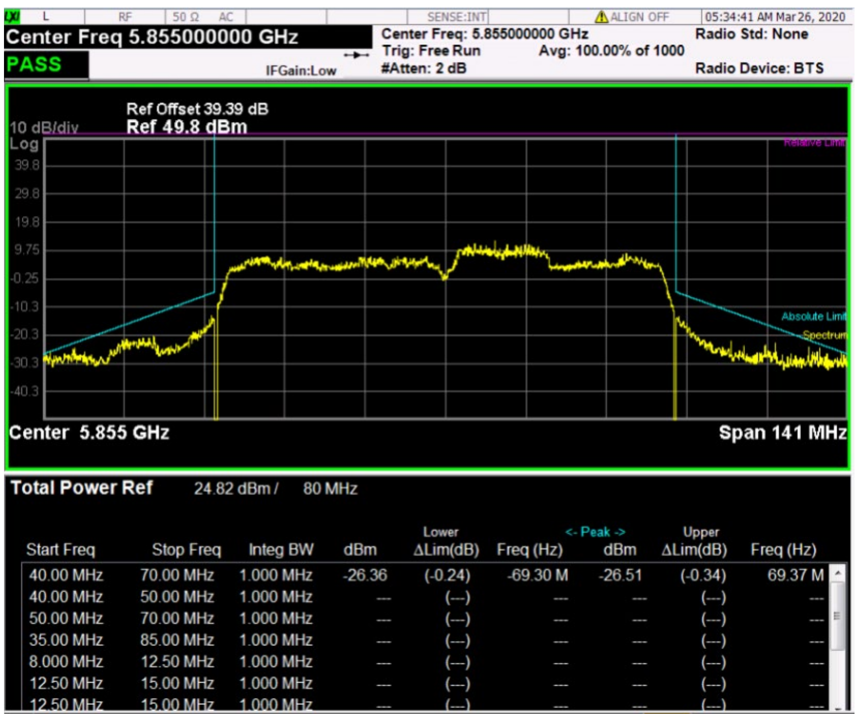
Average RMS Power measured in CH 180 and CH 183



Key Settings: Avg Detector, RMS Avg

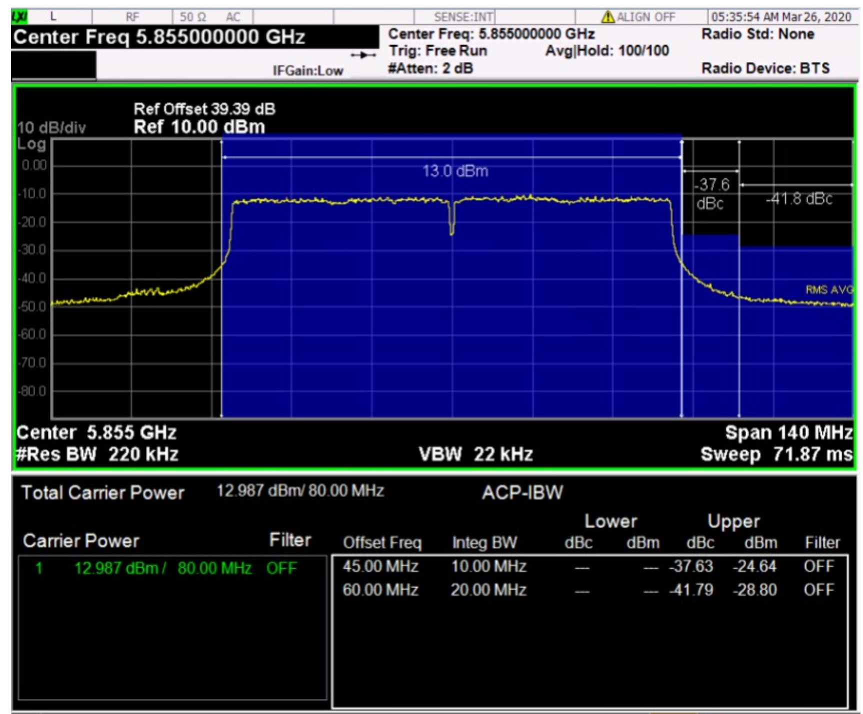
802.11ac Devices, CH 171 (80 MHz) – TX Power Adjusted to Meet Proposal 1 Mask

OOBE - Proposal 1 SEM (Proposed)



Key Settings: Res BW: 1 MHz, Max Hold, Peak Detector

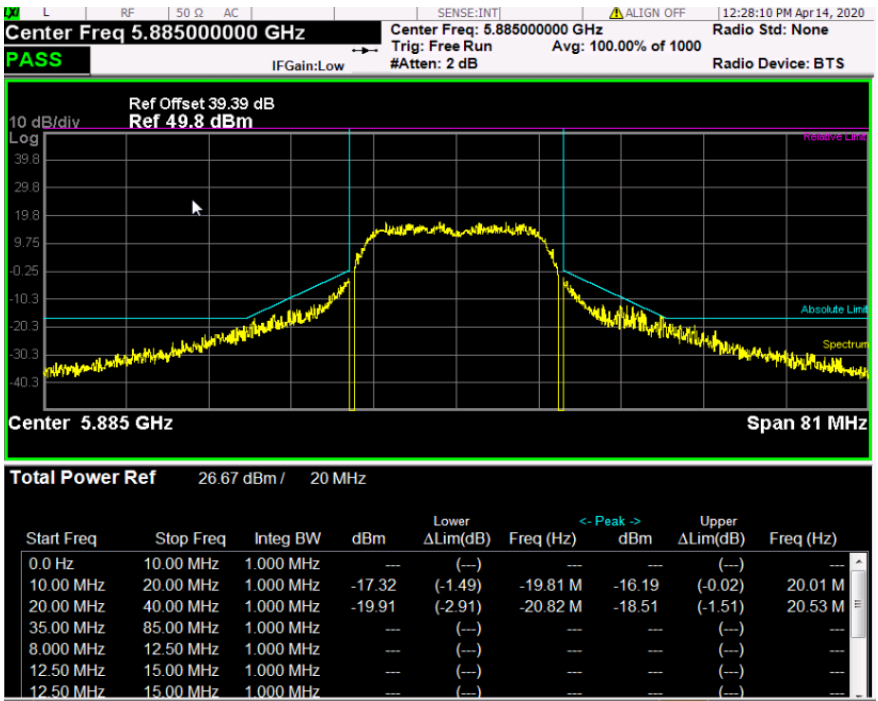
Average RMS Power measured in CH 180 and CH 183



Key Settings: Avg Detector, RMS Avg

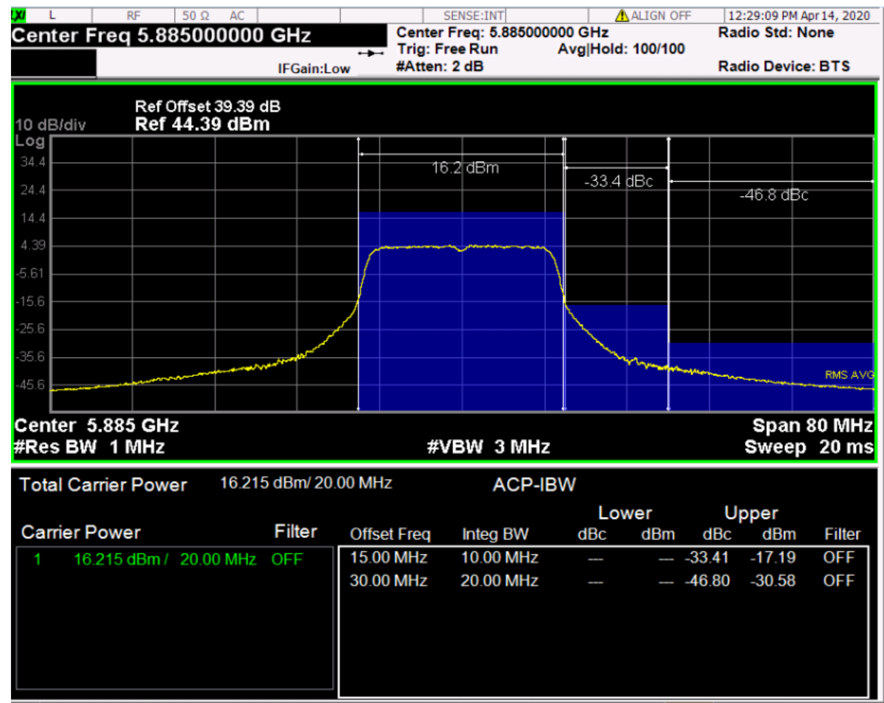
802.11ac Devices, CH 177 (20 MHz) – TX Power Adjusted to Meet Proposal 2 Mask

OOBE - Proposal 2SEM (Proposed)



Key Settings: Res BW: 1 MHz, Max Hold, Peak Detector

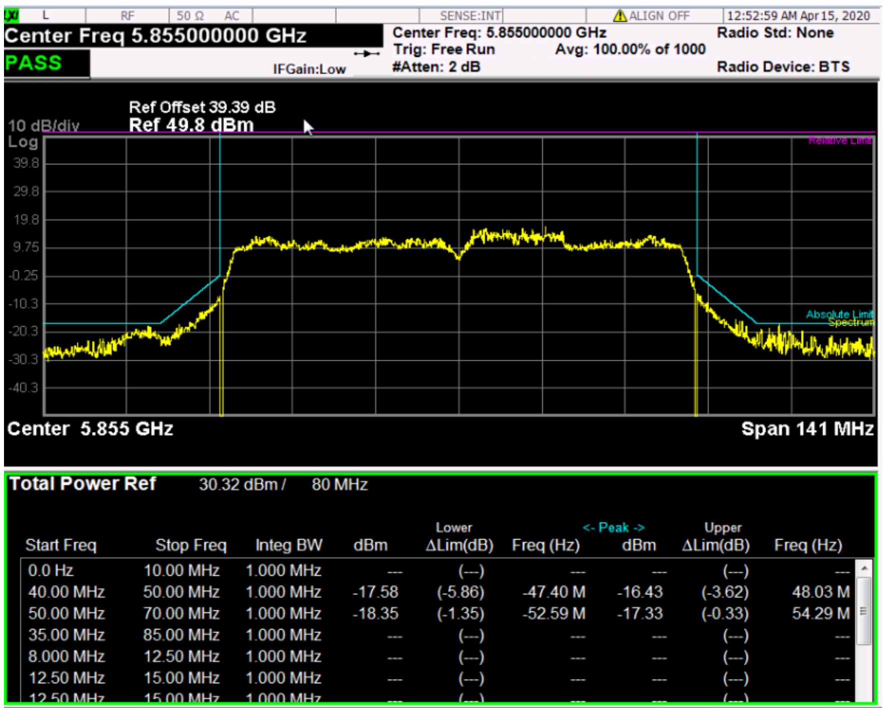
Average RMS Power measured in CH 180 and CH 183



Key Settings: Avg Detector, RMS Avg

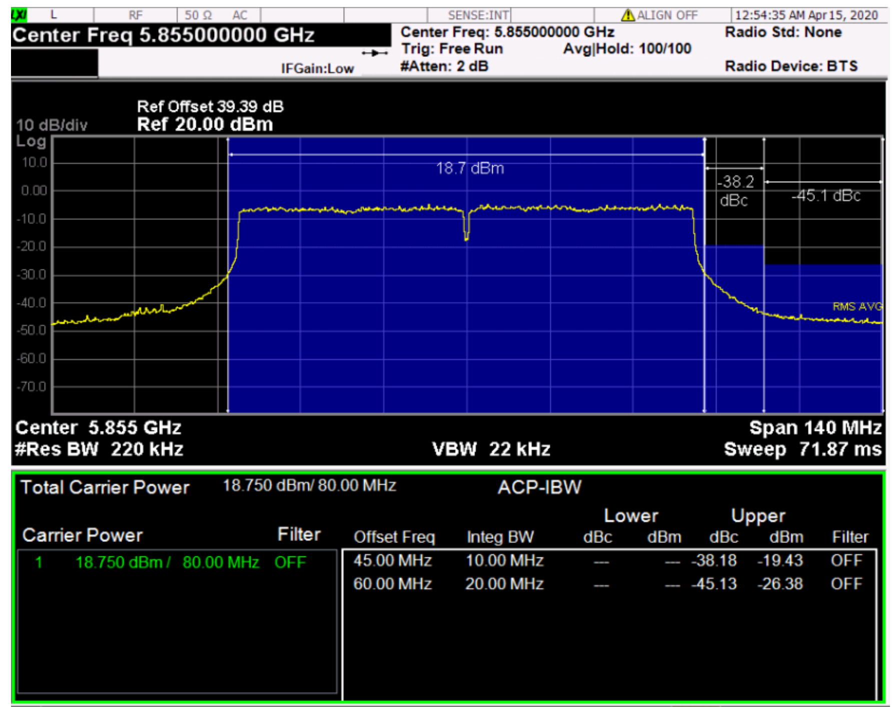
802.11ac Devices, CH 171 (80 MHz) – TX Power Adjusted to Meet Proposal 2 Mask

OOBE – Proposal 2 SEM (Proposed)



Key Settings: Res BW: 1 MHz, Max Hold, Peak Detector

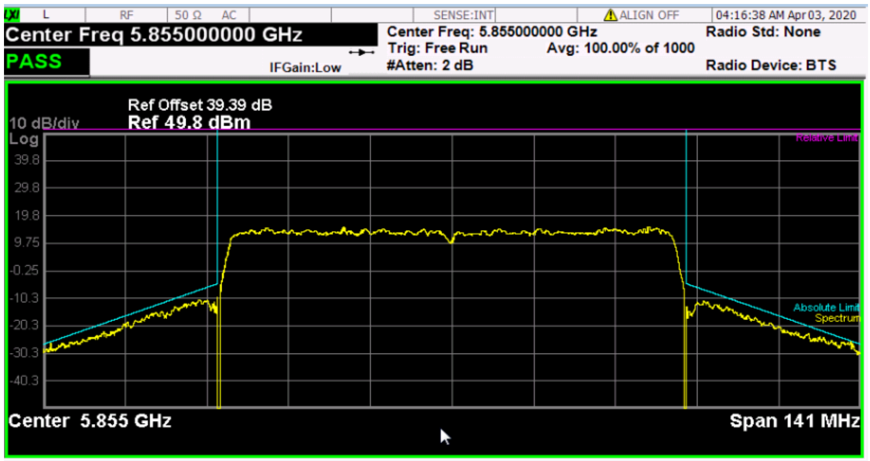
Average RMS Power measured in CH 180 and CH 183



Key Settings: Avg Detector, RMS Avg

Generated 802.11ac Waveform, CH 171 (80 MHz) – TX Power Adjusted to Meet Proposal 1 Mask

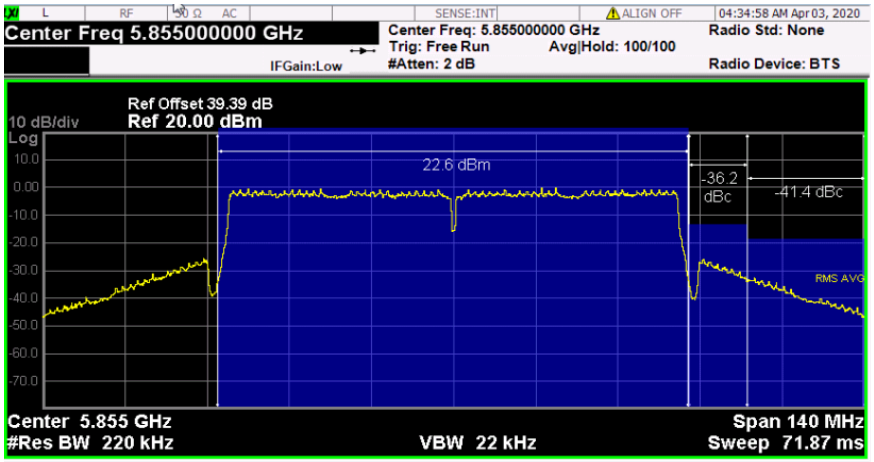
OOBE - Proposal 1 SEM (Proposed)



Start Freq	Stop Freq	Integ BW	dBm	Lower ΔLim(dB)	Freq (Hz)	dBm	Upper ΔLim(dB)	Freq (Hz)
40.00 MHz	70.00 MHz	1.000 MHz	-26.72	(-0.70)	-69.16 M	-25.80	(-0.04)	68.81 M
40.00 MHz	50.00 MHz	1.000 MHz	---	(---)	---	---	(---)	---
50.00 MHz	70.00 MHz	1.000 MHz	---	(---)	---	---	(---)	---
35.00 MHz	85.00 MHz	1.000 MHz	---	(---)	---	---	(---)	---
8.000 MHz	12.50 MHz	1.000 MHz	---	(---)	---	---	(---)	---
12.50 MHz	15.00 MHz	1.000 MHz	---	(---)	---	---	(---)	---
12.50 MHz	15.00 MHz	1.000 MHz	---	(---)	---	---	(---)	---

Key Settings: Res BW: 1 MHz, Max Hold, Peak Detector

Average RMS Power measured in CH 180 and CH 183



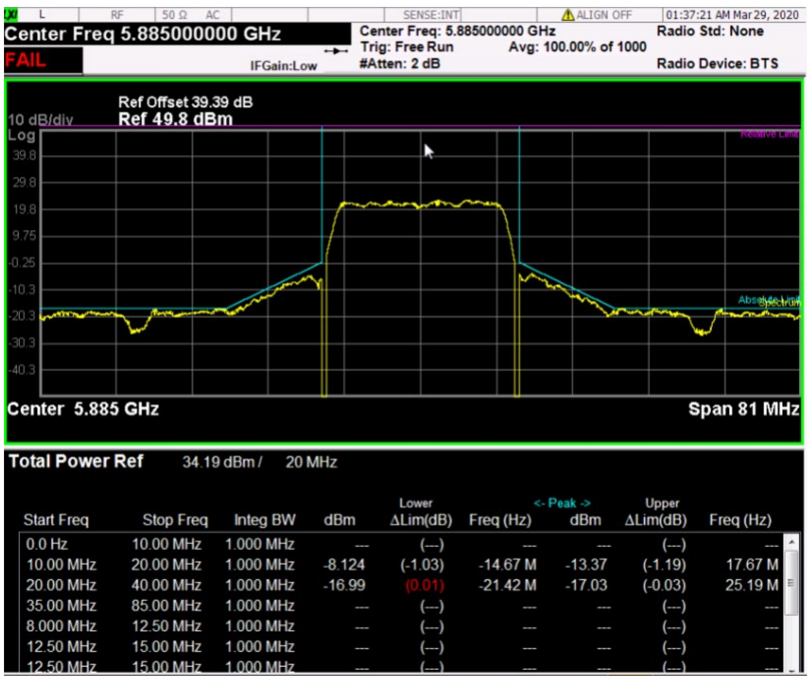
Carrier Power		Filter
1	22.614 dBm / 80.00 MHz	OFF

Offset Freq	Integ BW	Lower dBc	Lower dBm	Upper dBc	Upper dBm	Filter
45.00 MHz	10.00 MHz	---	---	-36.15	-13.54	OFF
60.00 MHz	20.00 MHz	---	---	-41.35	-18.74	OFF

Key Settings: Avg Detector, RMS Avg

Generated 802.11ac Waveform, CH 177 (20 MHz) – TX Power Adjusted to Meet Proposal 2 Mask

OOBE – Proposal 2 SEM (Proposed)



Key Settings: Res BW: 1 MHz, Max Hold, Peak Detector

Average RMS Power measured in CH 180 and CH 183

Key Settings: Avg Detector, RMS Avg

Interference (RMS Power) Summary

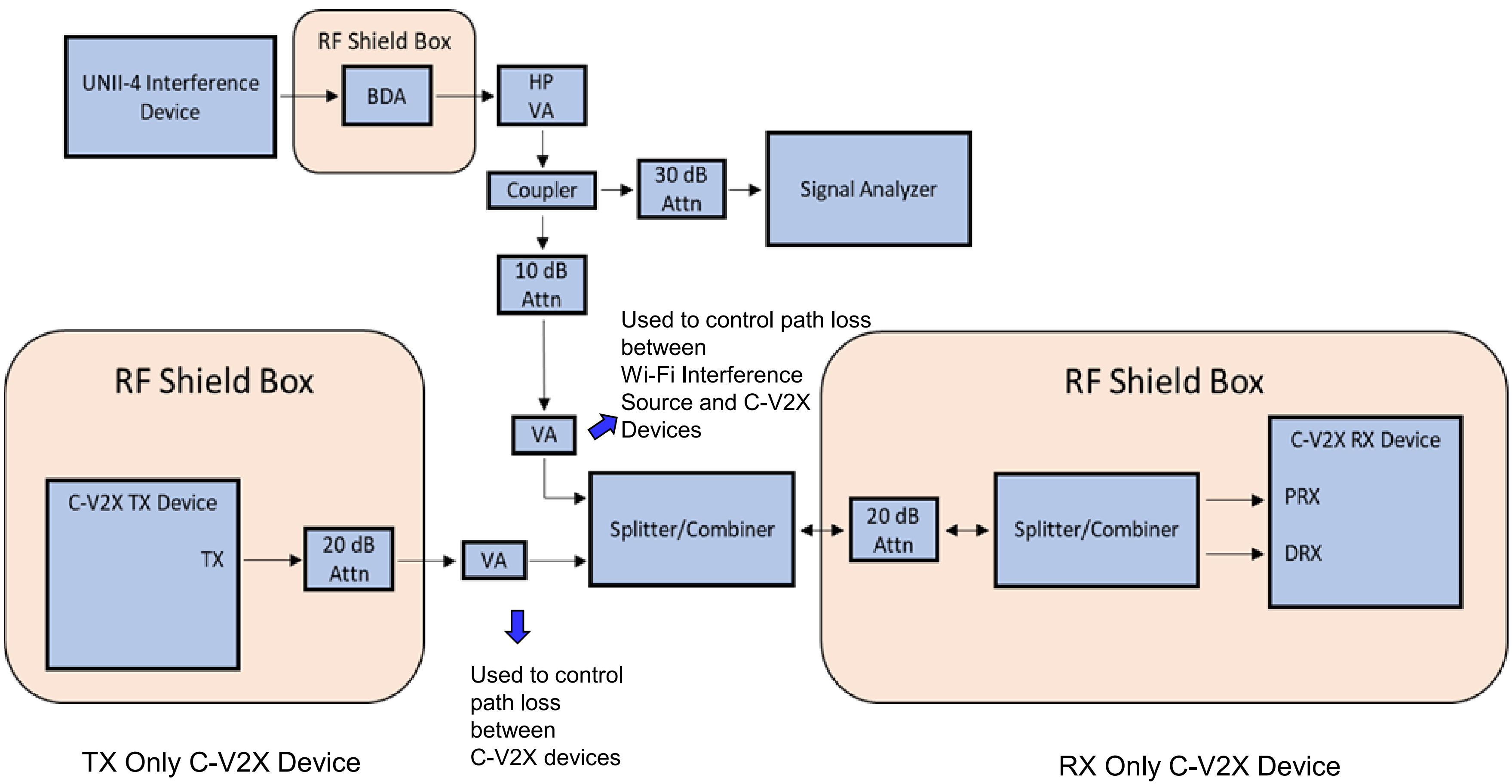
Interferer Profile	In band RMS Power (dBm)	RMS Power Measured in CH 180 (dBm)	RMS Power Measured in CH 183 (dBm)
CH 177 (20 MHz), 802.11ac Devices, Proposal 1 Mask	13.25	-20.01	-32.99
CH 171 (80 MHz), 802.11ac Devices, Proposal 1 Mask	12.99	-24.64	-28.80
CH 177 (20 MHz), , 802.11ac Devices, Proposal 2 Mask	16.2	-17.2	-30.6
CH 171 (80 MHz), 802.11ac Devices, Proposal 2 Mask	18.75	-19.43	-26.38
CH 171 (80 MHz), Generated 802.11ac, Proposal 1 Mask	22.61	-13.54	-18.74
CH 177 (20 MHz), Generated 802.11ac, Proposal 2 Mask	24.31	-9.67	-16.84

- Since the 20 MHz 802.11ac Wi-Fi Device Operation causes more interference to Channel 180 as compared to 80 MHz operation, it is used as the interference bandwidth in the following tests when assessing impact to CH 180.
- Similarly, 80 MHz 802.11ac Wi-Fi operation of Wi-Fi devices is chosen as the interference bandwidth for CH 183 testing.
- For Generated waveforms, the same configuration is used for both CH 180 and CH 183.

Bench Testing Objective

- Characterize impact to baseline sensitivity of the C-V2X receiver under test from Wi-Fi interference at varying path loss/isolation from the C-V2X receiver
- Sensitivity is defined as min RX power (dBm) required to maintain PER below 10% threshold for configuration under test

Bench Testing Setup



Bench Testing Procedure

- Baseline Sensitivity of the configuration under test is determined by turning off the interference and adjusting the path loss between C-V2X transmitter and receiver
  - For each path loss setting between C-V2X transmitter and receiver, PER is determined over 10,000 packets
- Wi-Fi Interference is introduced at the receiver for varying levels of path loss between Wi-Fi interferer and C-V2X receiver [60 dB to 110 dB in 10 dB steps]
- For each path loss setting between Wi-Fi interferer and C-V2X receiver, the sensitivity for the C-V2X configuration is determined
  - For each path loss setting between C-V2X transmitter and receiver, PER is determined over 10,000 packets
- Tests are repeated for different interferer proposals

Bench Test Scenarios

Interferer Profile	C-V2X Channel	C-V2X Packet Size (bytes)
20 MHz CH 177, 802.11ac Devices, Proposal 1 Mask	CH 180	365
20 MHz CH 177, 802.11ac Devices, Proposal 1 Mask	CH 180	1400
20 MHz CH 177, 802.11ac Devices, Proposal 2 Mask	CH 180	365
20 MHz CH 177, 802.11ac Devices, Proposal 2 Mask	CH 180	1400
80 MHz CH 171, 802.11ac Devices, Proposal 1 Mask	CH 183	365
80 MHz CH 171, 802.11ac Devices, Proposal 1 Mask	CH 183	1400
80 MHz CH 171, 802.11ac Devices, Proposal 2 Mask	CH 183	365
80 MHz CH 171, 802.11ac Devices, Proposal 2 Mask	CH 183	1400
20 MHz CH 177, Generated 802.11ac Waveform , Proposal 2 Mask	CH 180	365
20 MHz CH 177, Generated 802.11ac Waveform , Proposal 2 Mask	CH 180	1400
20 MHz CH 177, Generated 802.11ac Waveform , Proposal 2 Mask	CH 183	365
20 MHz CH 177, Generated 802.11ac Waveform , Proposal 2 Mask	CH 183	1400
80 MHz CH 171, Generated 802.11ac Waveform , Proposal 1 Mask	CH 180	365
80 MHz CH 177, Generated 802.11ac Waveform , Proposal 1 Mask	CH 180	1400
80 MHz CH 171, Generated 802.11ac Waveform , Proposal 1 Mask	CH 183	365
80 MHz CH 171, Generated 802.11ac Waveform , Proposal 1 Mask	CH 183	1400

Selected Results*

*See Appendix for individual test results

Wi-Fi Devices v/s Generated Waveform Proposal 1 Mask, C-V2X CH 180

	Wi-Fi Devices		Generated Wi-Fi Waveform	
Isolation / Path Loss (dB)	10% PER CH180 365 bytes (dBm)	10% PER CH180 1400 bytes (dBm)	10% PER CH180 365 bytes (dBm)	10% PER CH180 1400 bytes (dBm)
Baseline	-99.35	-98.35	-99.35	-98.35
110	-99.35	-98.35	-100.35	-98.35
100	-99.35	-98.35	-99.35	-98.35
90	-99.35	-98.35	-98.35	-97.35
80	-98.35	-96.35	-92.45	-92.45
70	-93.35	-88.45	-83.45	-83.45
60	-85.45	-80.35	-73.25	-73.25

Note: Yellow Highlight shows the range where significant impact from interference starts to be noticed. For example, for the Wi-Fi Devices, 365 byte packet at 70dB isolation, the sensitivity of the C-V2X receiver is reduced by 6dB which in practical terms might mean up to 50% range in LOS conditions

Wi-Fi Devices v/s Generated Waveform Proposal 1 Mask, C-V2X CH 183

	Wi-Fi Devices		Generated Wi-Fi Waveform	
Isolation / Path Loss (dB)	10% PER CH183 365 bytes (dBm)	10% PER CH183 1400 bytes (dBm)	10% PER CH183 365 bytes (dBm)	10% PER CH183 1400 bytes (dBm)
Baseline	-98.25	-95.15	-98.25	-95.15
110	-98.25	-95.15	-98.25	-94.25
100	-99.25	-95.15	-98.25	-93.25
90	-98.25	-95.15	-98.25	-94.25
80	-99.25	-94.25	-97.25	-93.25
70	-96.25	-93.25	-91.25	-87.25
60	-93.25	-89.25	-82.35	-78.15

Wi-Fi Devices v/s Generated Waveform Proposal 2 Mask, C-V2X CH 180

	Wi-Fi Devices		Generated Wi-Fi Waveform	
Isolation / Path Loss (dB)	10% PER CH180 365 bytes (dBm)	10% PER CH180 1400 bytes (dBm)	10% PER CH180 365 bytes (dBm)	10% PER CH180 1400 bytes (dBm)
Baseline	-99.35	-98.35	-99.35	-98.35
110	-99.35	-98.35	-99.35	-98.35
100	-99.35	-98.35	-99.35	-98.35
90	-98.35	-97.35	-97.35	-96.35
80	-96.35	-93.35	-89.35	-89.35
70	-91.35	-86.45	-80.35	-80.35
60	-82.25	-76.25	-72.25	-70.15

Wi-Fi Devices v/s Generated Waveform Proposal 2 Mask, C-V2X CH 183

	Wi-Fi Devices		Generated Wi-Fi Waveform	
Isolation / Path Loss (dB)	10% PER CH183 365 bytes (dBm)	10% PER CH183 1400 bytes (dBm)	10% PER CH183 365 bytes (dBm)	10% PER CH183 1400 bytes (dBm)
Baseline	-98.25	-95.15	-98.25	-95.15
110	-97.25	-94.25	-99.25	-94.25
100	-98.25	-94.25	-99.25	-94.25
90	-97.25	-94.25	-98.25	-94.25
80	-98.25	-93.25	-97.25	-93.25
70	-96.25	-86.35	-90.25	-86.35
60	-91.25	-77.15	-80.25	-77.15

Bench Testing Summary

- C-V2X receiver sensitivity in CH 180 can be impacted by U-NII-4 Wi-Fi operation when path loss to interferer is less than 90dB

- C-V2X receiver sensitivity in CH 183 can be impacted by U-NII-4 Wi-Fi operation when path loss to interferer is less than 80dB

- Proposal 2 is expected to provide additional level of protection to C-V2X operation in CH 180 and CH 183 as it proposes to restrict U-NII-4 Wi-Fi to indoor operation

Note: Field testing to further characterize interference is planned.

Next Steps

- Execute Field Tests to collect empirical data from the field

Appendix

Test Results for Individual Scenarios

Interpreting the Results

- Calculated Interference Power in CH 180 is total power in 10 MHz . (Path loss + Avg rms power measured in CH 180)
- Calculated Interference Power in CH 183 is total power in 20 MHz (Path loss + Avg rms power measured in CH 183)
- Interference power is not uniformly distributed in CH 180 and CH 183. Refer to Wi-Fi device characterization for details.
- 365 byte messages use only 2 sub-channels = 20 RB = 3.6 MHz bandwidth
- 1400 byte messages use 5 subchannels for CH 180 and 10 sub-channels for CH 183

802.11ac Devices, CH 177 (20 MHz), Proposal 1 Mask , C-V2X CH 180

C-V2X: (MCS 11, 365 bytes, 2 sub-channels), (MCS 7, 1400 bytes, 5 sub-channels, 2 segments)

Interference Duty Cycle : ~90%

Interference CH 180 RMS avg power before isolation: -20 dBm (-30 dBm/MHz)

Isolation / Path Loss (dB)	CH 180 Calculated Interference Avg Power at RX (10 MHz) (dBm)	10% PER CH180 365 bytes (dBm)	10% PER CH180 1400 bytes (dBm)
Baseline		-99.35	-98.35
110	-130	-99.35	-98.35
100	-120	-99.35	-98.35
90	-110	-99.35	-98.35
80	-100	-98.35	-96.35
70	-90	-93.35	-88.45
60	-80	-85.45	-80.35

802.11ac Devices, CH 171 (80 MHz), Proposal 1 Mask , C-V2X CH 183

C-V2X: (MCS 11, 365 bytes, 2 sub-channels), (MCS7, 1400 bytes, 10 sub-channels)

Interference Duty Cycle : ~90%

Interference CH 180 RMS avg power before isolation: -28.80 dBm (-41.80 dBm/MHz)

Isolation (dB)	CH 183 Calculated Interference Avg Power at RX (20 MHz) (dBm)	10% PER CH183 365 bytes (dBm)	10% PER CH183 1400 bytes (dBm)
Baseline		-98.25	-95.15
110	-138.80	-98.25	-95.15
100	-128.80	-99.25	-95.15
90	-118.80	-98.25	-95.15
80	-108.80	-99.25	-94.25
70	-98.80	-96.25	-93.25
60	-88.80	-93.25	-89.25

802.11ac Devices, CH 177 (20 MHz), Proposal 2 Mask , C-V2X CH 180

C-V2X: (MCS 11, 365 bytes, 2 sub-channels), (MCS7, 1400 bytes, 5 sub-channels, 2 segments)

Interference Duty Cycle : ~90%

Interference CH 180 RMS avg power before isolation: -17.2 dBm (-27.2 dBm/MHz)

Isolation (dB)	CH 180 Calculated Interference Avg Power at RX (10 MHz) (dBm)	10% PER CH180 365 bytes (dBm)	10% PER CH180 1400 bytes (dBm)
Baseline		-99.35	-98.35
110	-127.2	-99.35	-98.35
100	-117.2	-99.35	-98.35
90	-107.2	-98.35	-97.35
80	-97.2	-96.35	-93.35
70	-87.2	-91.35	-86.45
60	-77.2	-82.25	-76.25

802.11ac Devices, CH 171 (80 MHz), Proposal 2 Mask , C-V2C CH 183

C-V2X: (MCS 11, 365 bytes, 2 sub-channels), (MCS7, 1400 bytes, 10 sub-channels)

Interference Duty Cycle : ~90%

Interference CH 180 RMS avg power before isolation: -26.38 dBm (--39.38 dBm/MHz)

Isolation (dB)	CH 183 Calculated Interference Avg Power at RX (20 MHz) (dBm)	10% PER CH183 365 bytes (dBm)	10% PER CH183 1400 bytes (dBm)
Baseline		-98.25	-95.15
110	-136.38	-97.25	-94.25
100	-126.38	-98.25	-93.25
90	-116.38	-97.25	-94.25
80	-106.38	-98.25	-94.25
70	-96.38	-96.25	-92.35
60	-86.38	-91.25	-87.25

Generated 802.11ac Waveform, CH 171 (80 MHz), Proposal 1 Mask , C-V2X CH 180

C-V2X: (MCS 11, 365 bytes, 2 sub-channels), (MCS7, 1400 bytes, 5 sub-channels, 2 Segments)

Interference Duty Cycle : ~60%

Interference CH 180 RMS avg power before isolation: -13.54 dBm (-23.54 dBm/MHz)

Isolation (dB)	CH 180 Calculated Interference Avg Power at RX (10 MHz) (dBm)	10% PER CH180 365 bytes (dBm)	10% PER CH180 1400 bytes (dBm)
Baseline		-99.35	-98.35
110	-123.54	-100.35	-98.35
100	-113.54	-99.35	-98.35
90	-103.54	-98.35	-97.35
80	-93.54	-92.45	-92.45
70	-83.54	-83.45	-83.45
60	-73.54	-73.25	-73.25

Generated 802.11ac Waveform, CH 171 (80 MHz), Proposal 1 Mask , C-V2X CH 183

C-V2X: (MCS 11, 365 bytes, 2 sub-channels), (MCS7, 1400 bytes, 10 sub-channels)

Interference Duty Cycle : ~60%

Interference CH 183 RMS avg power before isolation: -18.74 dBm (-31.74 dBm/MHz)

Isolation (dB)	CH 183 Calculated Interference Avg Power at RX (20 MHz) (dBm)	10% PER CH183 365 bytes (dBm)	10% PER CH183 1400 bytes (dBm)
Baseline		-98.25	-95.15
110	-128.74	-98.25	-94.25
100	-118.74	-98.25	-93.25
90	-108.74	-98.25	-94.25
80	-98.74	-97.25	-93.25
70	-88.74	-91.25	-87.25
60	-78.74	-82.35	-78.15

Generated 802.11ac Waveform, CH 177 (20 MHz), Proposal 2 Mask , C-V2X CH 180

C-V2X: (MCS 11, 365 bytes, 2 sub-channels), (MCS7, 1400 bytes, 5 sub-channels, 2 Segments)

Interference Duty Cycle : ~55%

Interference CH 180 RMS avg power before isolation: -9.7 dBm (-22.7 dBm/MHz)

Isolation (dB)	CH 180 Calculated Interference Avg Power at RX (10 MHz) (dBm)	10% PER CH180 365 bytes (dBm)	10% PER CH180 1400 bytes (dBm)
Baseline		-99.35	-98.35
110	-119.7	-99.35	-98.35
100	-109.7	-99.35	-98.35
90	-99.7	-97.35	-96.35
80	-89.7	-89.35	-89.35
70	-79.7	-80.35	-80.35
60	-69.7	-72.25	-70.15

Generated 802.11ac Waveform, CH 177 (20 MHz), Proposal 2 Mask , C-V2X CH 183

C-V2X: (MCS 11, 365 bytes, 2 sub-channels), (MCS7, 1400 bytes, 10 sub-channels)

Interference Duty Cycle : ~55%%

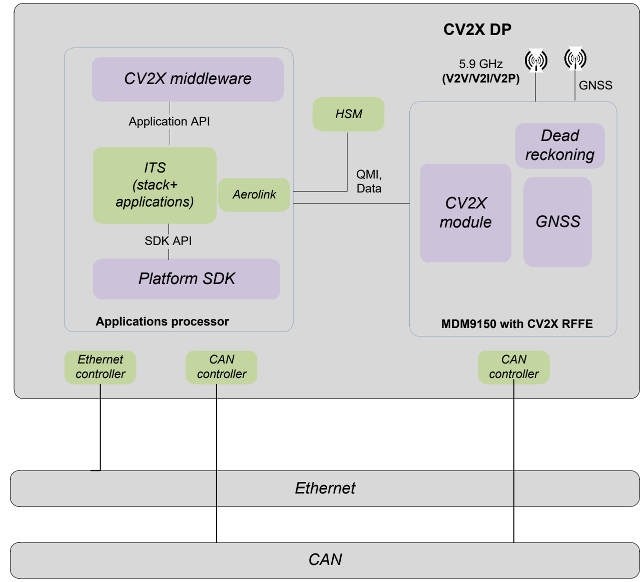
Interference CH 180 RMS avg power before isolation: -16.84 dBm (-29.84 dBm/MHz)

Isolation (dB)	CH 183 Calculated Interference Avg Power at RX (20 MHz) (dBm)	10% PER CH183 365 bytes (dBm)	10% PER CH183 1400 bytes (dBm)
Baseline		-98.25	-95.15
110	-117.84	-99.25	-94.25
100	-116.84	-99.25	-94.25
90	-106.84	-98.25	-94.25
80	-96.84	-97.25	-93.25
70	-86.84	-90.25	-86.35
60	-76.84	-80.25	-77.15

Devices Used

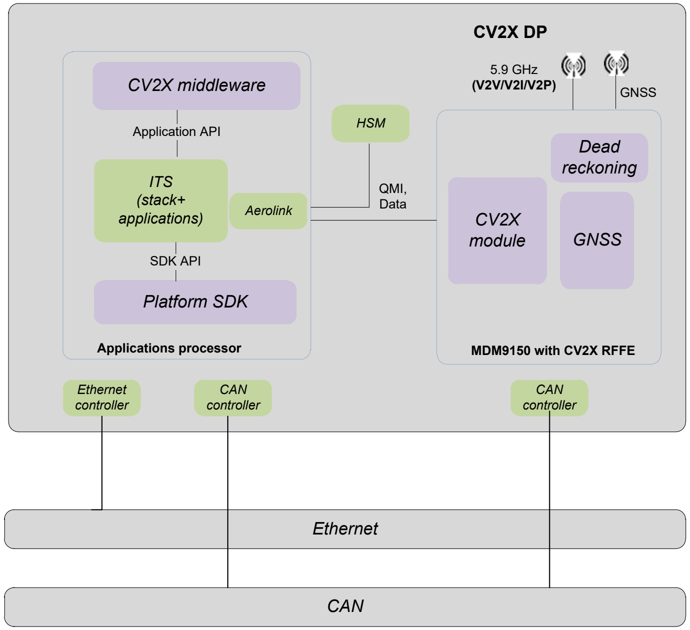
C-V2X Development Platform (RRv1)

- Objectives
  - Serve as early OBU or RSU for C-V2X evaluation, trials and demonstration
  - Enable ITS stack vendors to port their stack and applications to function over the C-V2X PC5 Direct Communications
- Description
  - Platform consists of APQ 8096 (Applications Processor) and C-V2X 3GPP Single Channel Radio MDM 9160
  - Platform SDK to enable ITS stack vendors
  - Evaluation units supplied by Qualcomm come pre-loaded with ITS stack and applications from Savari
    - V2V Applications: FCW, EEBL, IMA, LTA, BSW, LCW
    - V2I Applications: SPAT/MAP etc.
  - Test Applications built using Platform SDK are also available for PC5 evaluation independent of ITS stack
  - CAN Functionality
    - Provides Multiple CAN buses and Multiple Options to connect to the Vehicle CAN Bus
  - Optional C-V2X Middleware to enable V2I, V2P, V2N Applications



C-V2X Development Platform (RRv1)

Component	Description
Processor	Automotive Snapdragon820 (APQ8996) 1200 MHz ARM A7 (in MDM9150)+B2
Memory	2 GB (APQ)
Storage	64 GB + 2 GB, microSD slot
Radio	PC5 Mode 4
GNSS	Multi-constellation Qualcomm QDR3 Dead Reckoning XTRA + Time injection
Operational Temperature	“-40 to 85C”
Other Interfaces	USB 3.0 OTG, USB Host, 3x 1 Mbps CAN, 1000BT Ethernet, RS232
Standards	3GPP Rel 14, IEEE 1609.3, ETSI ITS G5, SAE J2735, SAE J3161 (draft)
Security	IEEE 1609.2 (Via Savari & OnBoard Security)
Wireless Connectivity	Automotive QCA6574AU - Wi-Fi: 2.4 GHz, 802.11n, 2 x 2 - Bluetooth 4.2 + BLE



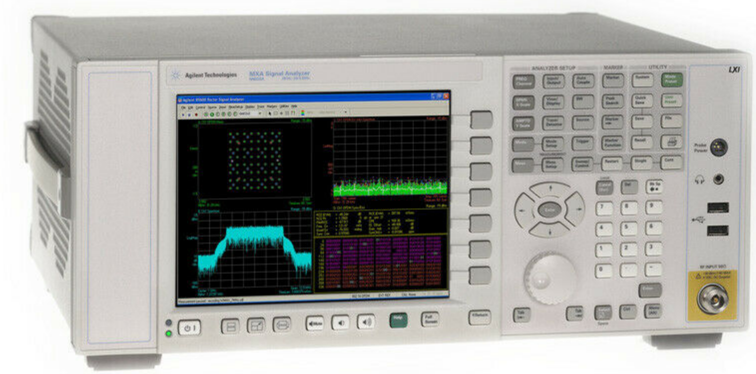
Wi-Fi Devices

- 802.11ac Wi-Fi Router
  - QCA AP161 Development Platform
    - QCA 9984 5GHz Radio

Test Equipment

- Vector Signal Generator
  - R&S SMBV 100

- Signal Analyzer
  - Keysight MXA 9020A



Attachment 3

Protecting 5.9 GHz C-V2X operations from 6 GHz unlicensed In-Vehicle VLP and Mobile Hotspots in the U-NII-5 band

ET Docket No. 18-295

November 12, 2020

Overview and Summary

- 5GAA has filed studies demonstrating that the -27 dBm/MHz OOBE level applicable to 6 GHz fixed outdoor APs[1] and indoor unlicensed equipment will render unusable 5.9 GHz C-V2X reception if that level is radiated from in-vehicle unlicensed U-NII-5 equipment[1]
  - In-vehicle U-NII-5 operations provide key VLP and mobile AFC use cases as unlicensed advocates explain
  - 33 dB additional isolation beyond the -27 dBm/MHz level is needed to protect C-V2X reception, and can be accomplished by requiring unlicensed in-vehicle devices to avoid the lowermost U-NII-5 channel or by imposing a 33 dB more stringent OOBE level on in-vehicle U-NII-5 operations
- The CAMP C-V2X Consortium Test Results using actual V2V communications (which 5GAA previously filed in the 5.9 GHz docket) further augment the 6 GHz record built by 5GAA and its members and support the need for much greater protection of C-V2X receivers from 6 GHz U-NII-5 in-vehicle operations, including VLP portables, peer-to-peer operations, and mobile AFC operations

1. *See, e.g.,* 5GAA Dec. 9, 2019 ex parte letter; 5GAA Jan. 9, 2020 ex parte letter; and 5GAA Jan. 24, 2020 ex parte letter, all filed in ET Docket No. 18-295.

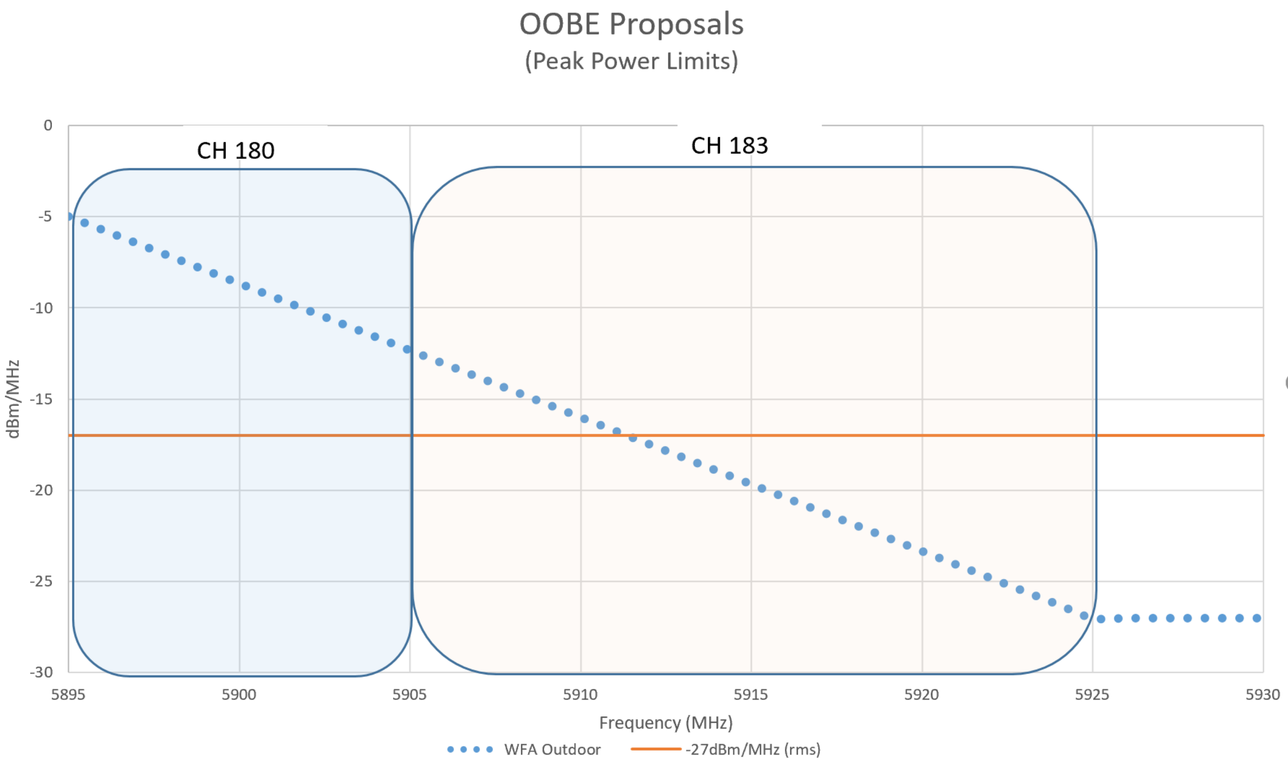
C-V2X Consortium Test Results Show In-Vehicle Unlicensed U-NII-5 Equipment Meeting a -27 dBm/MHz OOBE Level Will Interfere With C-V2X Reception in the 5.9 GHz Band

- The analysis here compares the interference to C-V2X receivers caused by the Wi-Fi Alliance (WFA) proposed outdoor OOBE levels -- published by the CAMP C-V2X Consortium[1,2] and presented by 5GAA to the FCC in the 5.9 GHz proceeding[3] -- to the -27 dBm/MHz rms OOBE level that applies to 6 GHz LPI and fixed outdoor standard power APs
  - C-V2X Consortium testing with the WFA proposed outdoor mask (based on peak levels) demonstrates harmful interference to C-V2X
  - The average OOBE signal power into 5905-5925 MHz C-V2X channel is comparable between the two masks with the -27 dBm/MHz flat OOBE mask having a slightly greater impact and similarly rendering the C-V2X service unreliable
- The impact of a flat OOBE signal mask of -27 dBm/MHz rms produces about the same harmful impact to C-V2X operations in 5905-5925 MHz as the WFA proposed OOBE outdoor mask that the CAMP C-V2X Consortium analyzed

1 https://pronto-core-cdn.prontomarketing.com/2/wp-content/uploads/sites/2896/2020/04/CAMP-CV2X_Project_Task_8_Final_04242020.pdf
2 https://pronto-core-cdn.prontomarketing.com/2/wp-content/uploads/sites/2896/2020/09/CAMP-CV2X-WiFi-Interference-Testing-Results-v6.11.3.pdf
3 5GAA C-V2X Consortium Testing Presentation w Attachment.pdf 38

Wi-Fi Signal Interference OOBE Comparison

- The figure shows the two emissions masks expressed in peak EIRP density
- A 10 dB peak to average ratio (p/a) is assumed for the interfering Wi-Fi signals, which translates the -27 dBm/MHz rms level to a -17 dBm/MHz peak level
  - The -27 dBm/MHz OOBE signal mask equals the -17 dBm/MHz (peak) level depicted as the orange line
  - The WFA outdoor OOBE mask is the blue dotted line in the graph and is the same as Proposal 1 depicted on slide 8 of the CAMP C-V2X Consortium Test Report[1]



1 https://pronto-core-cdn.prontomarketing.com/2/wp-content/uploads/sites/2896/2020/04/CAMP-CV2X_Project_Task_8_Final_04242020.pdf

WFA proposed 5.9 GHz OOBE mask vs -27 dBm/MHz rms

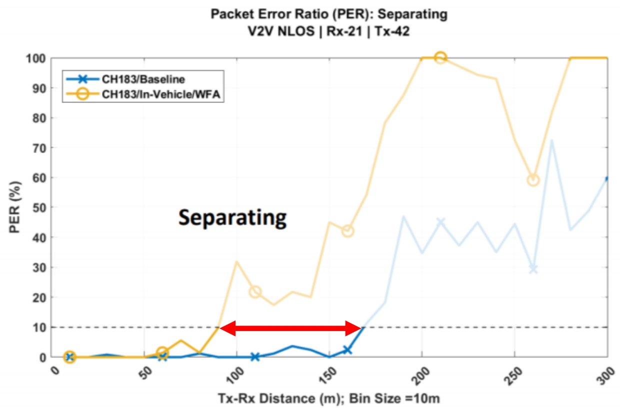
- CAMP C-V2X Consortium test results show:
  - WFA proposed 5.9 GHz outdoor OOBE mask results in lower average power in CH 183 as compared to an interferer with -17dBm/MHz peak OOBE profile (which translates to -27dBm/MHz rms assuming 10 dB peak to average ratio) (Slide 19 of C-V2X Consortium Test Results[1])
  - The C-V2X receiver has up to 2 dB better sensitivity (10% PER) performance in presence of an interferer with WFA mask as compared to interferer with -17 dBm/MHz peak (or -27dBm/MHz rms) (Slides 26 & 28)
  - At least 80 dB isolation is required to protect C-V2X from harmful interference from either the WFA proposed outdoor mask or the -17 dBm/MHz peak (or -27dBm/MHz rms level).
  - As noted above, the WFA proposed outdoor mask radiates less unwanted noise into the 5.9 GHz C-V2X band than the -27 dBm/MHz rms level that applies to fixed outdoor U-NII-5 equipment

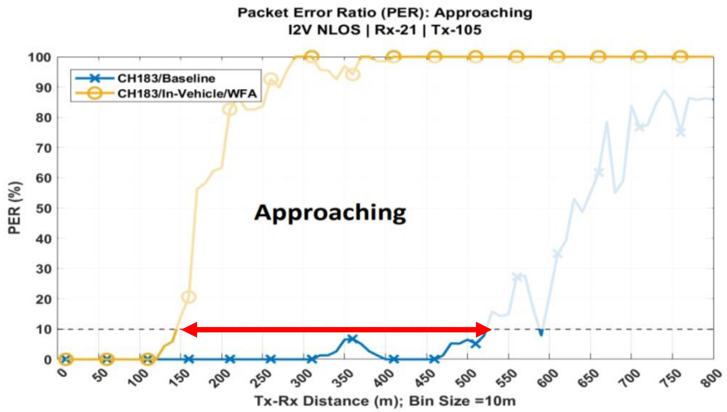
80 dB isolation is impossible to guarantee within the vehicle depending upon C-V2X antenna location and portable device location which can be within a meter of each other

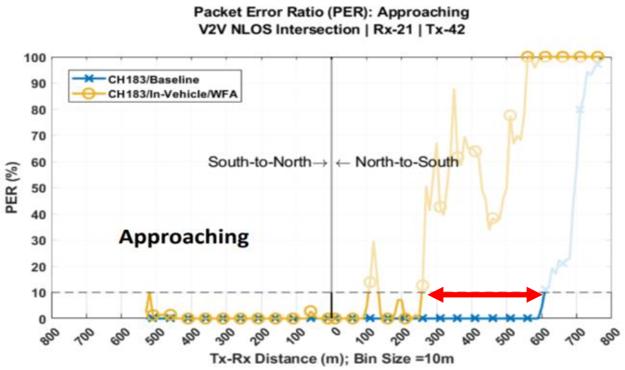
Source:
1 CAMP C-V2X Consortium Test Report available at https://pronto-core-cdn.prontomarketing.com/2/wp-content/uploads/sites/2896/2020/04/CAMP-CV2X_Project_Task_8_Final_04242020.pdf

CH 183 Impacts with the WFA Proposed Outdoor Mask

- In-Vehicle unlicensed U-NII-4 operations field test results published by the CAMP C-V2X Consortium show harmful interference to C-V2X operations in CH 183 from interferer meeting the WFA proposed outdoor mask (Slide 26 of C-V2X Consortium Interference Field Testing Results)
  - Up to 47% range reduction in V2V NLOS scenarios
  - Up to 71% range reduction in I2V NLOS scenarios
  - Up to 81% range reduction in V2V Intersection NLOS scenarios
- Impact to V2V Safety Applications in CH 183 has been noted (Slide 19 of deck linked above)
- Depending upon the relative positioning of the interferer and C-V2X antennas, the interference impact to C-V2X can be even worse







Conclusion

- The interference from an unlicensed interferer compliant with the OOBE outdoor mask proposed by the WFA in the 5.9 GHz proceeding is comparable to -- but less harmful than -- the interference caused by -27dBm/MHz rms OOBE that applies to fixed outdoor APs in the 6 GHz U-NII-5 band
- In-vehicle operations of U-NII-5 equipment meeting a -27 dBm/MHz rms OOBE level reduces V2V communications range by 81% in some use cases, rendering it unusable for vehicle safety communications; this confirms 5GAA's prior 6 GHz band advocacy and request for additional protection
- 5GAA requests that the FCC impose additional requirements on portable VLP and mobile AFC operations to ensure reliable reception of C-V2X safety messages if such operations are authorized
  - The FCC should require that the lowermost U-NII-5 channel be avoided by these portable/mobile devices and impose a Power Spectral Density Limit on U-NII-5 portables/mobiles to encourage the use of wideband channels (of 160 MHz and wider). Alternatively, the FCC can impose a -60 dBm/MHz OOBE level on these new U-NII-5 operations
  - The FCC should implement one of these protections now and could explore via an FNPRM potential means of allowing greater portable/mobile access to the U-NII-5 band while protecting the 5.9 GHz C-V2X band
  - Some potential solutions to study via an FNPRM include requiring unlicensed U-NII-5 devices to detect one or more of the following: (i) energy from adjacent channel C-V2X operations, (ii) in-vehicle motion, and (iii) location on or close to an active roadway – before beginning portable/mobile operations in the lower portion of the U-NII-5 band.